Some biological data on cetaceans populations present in the western coasts of Ireland

MÀSTER EN CIÈNCIA I TECNOLOGIA DE L'AIGUA

Treball de Recerca

Lídia Sarrà Alarcón

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Dra. Margarida Casadevall Maso, professora del Departament de Ciències Ambientals de la Universitat de Girona

CERTIFICA

Que *Lídia Sarrà Alarcón* ha realitzat, sota la seva direcció, el treball que, amb el títol "Some biological data on cetaceans populations present in the western coasts of Ireland", presenta en aquesta memòria, la qual constituirà el Treball de Recerca del màster

I perquè així consti signo el present certificat a

Girona, 5 de Febrer de 2010

Dra. Margarida Casadevall Masó

Prefaci

Aquest projecte ha estat realitzat gràcies a una beca LLP/Erasmus (de 3 mesos), i al conveni entre la Universitat de Girona i el Galway-Mayo Institute of Technology (GMIT) d'Irlanda.

L'objectiu inicial del projecte era relacionar la presència de determinats paràsits de la família Anisakidae en peixos d'interès pesquer, amb la freqüentació de cetacis en la zona d'estudi a les costes d'Irlanda. Els cetacis són els hostes definitius de molts d'aquests paràsits i per tant poden ser la causa de la seva major presència en determinades zones de pesca. Es volia també fer un anàlisi comparatiu dels resultats obtinguts amb dades disponibles pel Mediterrani. Durant el primer mes d'estada al Galway-Mayo Institute of Technology (GMIT) la meva feina consistia en anar recopilant tota la informació bibliogràfica disponible sobre el tema d'estudi. A més a més, també vaig començar a fer els primers contactes amb els experts en cetacis d'Irlanda que em podien ajudar a aconseguir mostres fresques mitjançant els varaments de les tres espècies proposades per a l'estudi; la marsopa de port (Harbour porpoise), el dofí comú (Short-beaked common dolphin) i el dofí mular (Bottlenose dolphin). Els varaments de cetacis tenen una alta freqüència durant tot l'any i a totes les costes irlandeses, però aquest any hi ha hagut un descens notable dels varaments més acusat en els últims mesos de l'any, fet que ha condicionat la disponibilitat de mostres fresques.

Per altra banda, semblava que seria fàcil disposar de dades de parasitació en les espècies d'interès pesquer de la zona i no va resultar ser així. Es per això que després de discutir amb les tutores la possibilitat de reorientar el treball, es va decidir afegir un altre aspecte relacionat amb la biologia dels cetacis, l'anàlisi de sons i la comunicació, fet que em permetria complementar també el meu aprenentatge durant la meva estada.

Per aquest motiu, el present treball es troba dividit en dues parts: la part de paràsits i la part d'acústica de cetacis.

Lídia Sarrà Alarcón

Acknowledgements

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Furthermore, I would like to thank Dr. Emer Rogan from University College Cork (UCC), Ireland, for allowing me to visit her and for the use of facilities at her Department. Also, thanks to Dr. Rogan for sharing non-published data collected by her student's on Anisakine parasites in marine mammals.

Thanks also to the School of Science and the International Office at GMIT, for the welcome they showed me and for providing me with facilities to undertake the research project.

Finally, I would like to thank my family for their constant support and for always encouraging me to never give up and to follow my dreams. Last but not least, thanks to all my friends for their kind and encouraging words. Many thanks go to my fellow postgraduates at GMIT: Jenni, John, Sophie, Melanie, Emma and Laura. It is a pity that three months go by so fast!!

Contents

<u>PART II: "A comparison of common dolphin, *Delphinus delphis*, Linnaeus (1758) whistles at two locations in Irish waters"</u>

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Abstract

Ireland's waters constitute one of the richest habitats for cetaceans in Europe. Marine mammals, particularly cetaceans, are known to be definitive hosts of digestive parasites from the Fm. Anisakidae. The main aim of this study is to collect and compile all the information available out there regarding parasites of the Fm. Anisakidae and their definitive hosts. Secondary objectives are to relate the presence of cetacean species with the presence of parasites of the Fm. Anisakidae and to determine whether this greater number of cetaceans relates to a greater level of parasitism. Prevalence and burdens of anisakids in definitive hosts vary widely with host species, geographic location, and season. Results from several post-mortem exams are given. However, they cannot be compared due to differences in collecting techniques. *Anisakis simplex* is the most commonly and widespread parasite found in the majority of the samples and in a major number of hosts, which include harbour porpoise, short-beaked common dolphin and bottlenose dolphin. Studies on harbour porpoise obtained prevalences of Anisakis spp. of 46% (n=26) and of 100% (n= 12). Another study in common dolphin reported a prevalence of 68% (n=25). Several reasons could influence the variations in the presence of Anisakis. Studies on commercially exploited fish have reported prevalences of *Anisakis simplex* ranging from 65-100% in wild Atlantic salmon and from 42-53.4% in Atlantic cod.

Keywords: cetaceans, strandings, nematodes, *Anisakis simplex*, prevalence.

1. Introduction

1.1 Cetacean strandings in Irish waters

Strandings all around Ireland have been reported since the 1900, with greater frequency on the south coast waters (Berrow & Rogan, 1997). Ireland's waters constitute one of the most important areas for cetaceans in Europe; where 24 cetacean species have been reported (O'Brien *et al*., 2009).

Marine mammals commonly strand or are washed ashore due to natural or human related causes. Stroud & Roffe (1979) reported that gunshot was the primary cause of death with a 30%. Bacterial infections and parasitism both accounted for 27% could cause the death or debilitation of Oregon marine mammals. Traumatic death or debilitation other than gunshot accounted for 16%. Other primary of contributory causes of strandings are predation, starvation due to neonatal abandonment, viral encephalitis, dystocia and neoplasia.

A stranding event may involve one individual (single stranding) or several animals (mass stranding). Also, animals may strand alive or dead (Berrow & Rogan, 1997). Tregenza *et al*. (1997) estimated that annually in the Celtic Sea 2200 porpoises and 200 common dolphins are caught due to bottom-set gillnets from Irish and UK vessels. In 1993, the Irish tuna fleet caught an estimate of 180-205 cetaceans, mainly common dolphins (Berrow & Rogan, 1998). In the Mediterranean, stranding reports from 1971 onwards, have confirmed the drastic decline that the Mediterranean sub-population of common dolphin has suffered in comparison with the striped dolphin, which has highly increased (Viale, 1994). The shift in cetaceans population occur in the Mediterranean may be due to (1) modification of the population structure; (2) changes of number and structure of each specific stock; (3) individual effects such as anatomical abnormalities leading to serious dysfunction.

In most cases stranding reports are the only source of information available on cetaceans' populations and also they can provide information for a longer time period and geographical area (Rogan & Berrow, 1997).

1.2 Cetaceans as final host for parasites of the Fm. Anisakidae

Parasites are not only common among humans; they are ubiquitous among all plant and animal groups (Bush *et al*., 2001). According to several authors a parasite is "an animal or plant living in or upon another organism, called host, obtaining its organic nutrients directly from it" (Chandler *&* Read, 1961; Rhode, 1993; Bush *et al*., 2001).

There are different types of parasites in relation to where they are attached to the host:

- Endoparasites: parasites confined within the host's body. Typically protozoans, digeneans, cestodes, nematodes and acanthocephalans (Chandler & Read*,* 1961; Rhode, 1993; Bush *et al*., 2001).
- Ectoparasites: parasites confined to the exterior of the host's body. Mainly arthropods and monogeneans (Chandler & Read*,* 1961; Rhode, 1993; Bush *et al*., 2001).

Not all the parasites can live in any host, there are several requirements that have to occur in order for the parasite to live in a host; (1) suitable conditions for access to the host and easy transmission from one host to another, (2) ability to establish itself in a host when it reaches one, (3) satisfactory conditions for growth and reproduction after it establishes itself (Chandler & Read*,* 1961). Furthermore, every parasite needs to have at least one species of host, and sometimes several and these conditions have to be satisfactorily met; otherwise the parasite would cease to exist (Bush *et al*., 2001).

There are several types of endoparasites but this study focuses on the nematode parasites of the digestive system. The parasites commonly enter the mouth as cysts, eggs or encapsulated larvae (Chandler & Read*,* 1961).

The Nematoda, commonly called roundworms, comprised of 256 families and more than 40,000 species and it is one of the largest and most successful groups in the animal kingdom (Geraci & Aubin, 1987; Rohde, 1993). Although most parasites are free-living, several species can parasite plants or animals (Bush *et al*., 2001; Rhode, 2005).

Nematodes are bilaterally symmetrical and generally take the form of an elongate cylinder tapered at each extremity and varying from less than 1mm to more than 1m in length at maturity (Rhode, 2005). Within the nematodes phylum there is a large and diverse order, called Ascaridida, whose adults' parasite the digestive tract in all vertebrate groups (Rhode, 1993). The majority of ascarids have direct life cycles; however, they may use an intermediate or paratenic host (or both), which may be either invertebrates or vertebrates (Bush *et al*., 2001).

There are different types of host:

- Intermediate: in which the parasites undergo some development and morphological change, but do not reach sexual maturity (Rhode, 1993; Bush *et al*., 2001). Normally a wide range of crustaceans, including copepods, amphipods, isopods, euphausiids, and decapods, and occasionally from polychaete worms and molluscs (Murrel & Fried, 2007).
- Paratenic or transport: a host which serves for dispersing the parasite species, but in which there is no development of the parasite (Rhode, 1993). Planktivores fish such as herring, haddock, blue whiting and juvenile plaice, mackerel and cod, and piscivores fish such as blue shark, barracuda, monkfish, and conger eel (Young, 1972; Bush *et al*., 2001; Murrel & Fried, 2007).
- Definitive or final: the organism in, or on, which a parasite reaches sexual maturity (Rhode, 1993; Bush *et al*., 2001; Murrel & Fried, 2007). Several species of birds, cetaceans and pinnipeds.

The order Ascaridida is divided into several families, with four families found in marine species: Acanthocheilidae, Anisakidae, Ascarididae and Heterocheilidae (Rhode, 1993). This study is going to focus on the Fm. Anisakidae.

1.2.1 Fm. Anisakidae

Species identification in the Anisakidae family has traditionally been complicated by a lack of distinguishing morphological characteristics, particularly in larval stages (Rhode, 2002; Murrel & Fried, 2007). The anisakids constitute those ascaridoids with an aquatic definitive host (e.g. fish, reptile, piscivorous fish and mammal) whose transmission is dependent on water and usually involves aquatic invertebrate and fish as intermediate or paratenic hosts (Murrel & Fried, 2007; Noguera *et al*., 2009).

According to Smith & Wootten (1978) the life cycle (**Fig. 1**) of Anisakids shows the following development characterized by four moults. The first moult evidently takes place within the eggs. The unembryonated eggs are mixed with the faeces of marine mammals and embryonate in sea water. They sink in sea water and may reach the seabed by the time of hatching, which varies depending on the local conditions e.g. upwelling of currents and temperature (Smith & Wootten, 1978). The second moult (L2) undergoes when the free-living larva emerges from the eggs. Then the larva enters the intermediate or paratenic hosts, where no moult occurs. There is evidence that the third (L3) and fourth moults (L4) undergoes in the final host. Once there, the parasite reaches adult stage. More recent studies stated that two moults occur within the egg and therefore the free-living larvae are second stage (L2) or third stage (L3). Also, the free-living larvae (L2 or L3) are ingested by invertebrates, mainly crustaceans, where it may undergo one moult (Murrel & Fried, 2007).

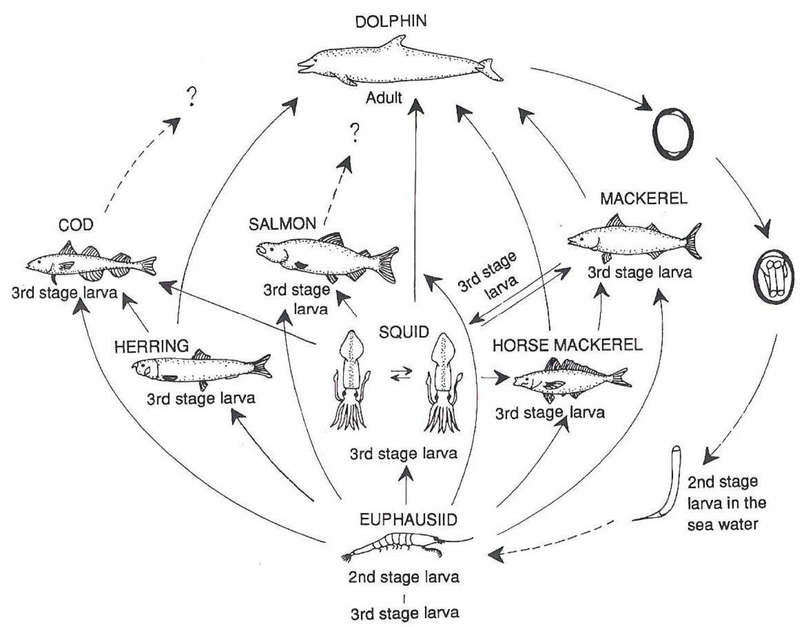

Figure 1. Life cycle of *Anisakis simplex* (Rhode, 1993).

Two factors may limit the distribution of larvae; the first one is the presence or absence of a suitable final host that will distribute the eggs and the second one is the absence of a first intermediate host (Young, 1972). Here it is where fisheries have a huge impact. Paratenic hosts are often important for human consumption (Bush *et al*., 2001). In Atlantic Canada in 1984, the processing cost attributable to *Pseudoterranova decipiens* infections was approximately $30 million (Bush *et al*., 2001).

The genus Anisakis, Contracaecum and Pseudoterranova are the most cosmopolitan parasites of marine mammals (Geraci & Aubin, 1987; Young 1972; Rhode, 1993; Bush et al., 2001; Rhode, 2002; Leger, 2007). Their life cycles are indirect, which involves marine crustaceans as intermediate hosts and a variety of fish and cephalopods as paratenic hosts (Young, 1972; Bush et al., 2001; Leger, 2007). Although there appear to be differences in host preference between different species, different parasitic species may be found in the same definitive host specie (Murrel & Fried, 2007).

Genus Anisakis

The Anisakis is the most common parasite and it has a worldwide distribution occurring in all major oceans and seas (Noguera *et al*., 2009), although individual species are in some cases more restricted in distribution (Smith & Wootten, 1978). *Anisakis simplex* (sensu stricto) is found in the North Atlantic Ocean between 30ºN and the Artic polar circle (Noguera *et al*., 2009); *Anisakis typica* is found from the Atlantic Ocean, Indian Ocean and Mediterranean Sea; *Anisakis physeteris* is found from the Atlantic and Mediterranean (Murrel & Fried, 2007).

According to Young (1972), *Anisakis simplex* (**Fig. 2**) occurs in 25 cetaceans and 11 pinnipeds species. Also, *Anisakis simplex* is more frequent in colder temperate and polar waters. On the contrary, *Anisakis typica* is restricted to warmer waters between 40ºN and 36ºS, a region where *A. simplex* is rare (Smith & Wootten, 1978; Murrel & Fried, 2007). However, *Anisakis physeteris* has only been recorded in 4 cetacean species, mostly sperm whale *Physeter catodon*, making its distribution worldwide (Smith & Wootten, 1978).

Anisakis parasites are found in almost all commercially exploited fish species in North Atlantic waters (Noguera *et al*., 2009). Burdens of *A. simplex* are highly variable and can be found to range from 2 to > 2000 (Rogan *et al*., 2001).

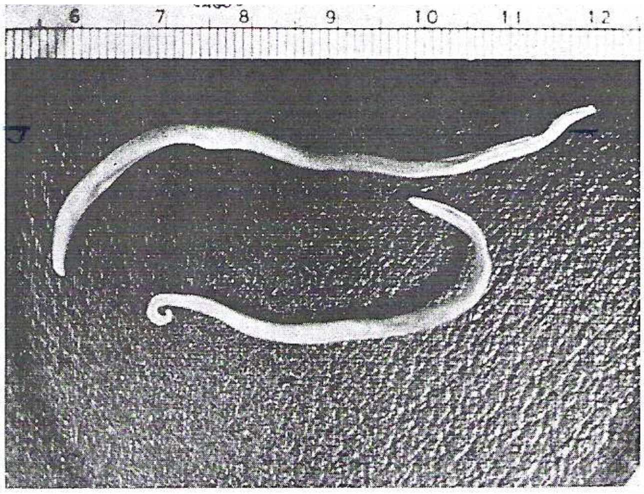

Figure 2. Adult male and female Anisakis simplex from the stomach of Tursiops truncatus (Dailey & Browell, 1972).

Genus Pseudoterranova

Pseudoterranova decipiens (sensu stricto) is found in the northeast Atlantic, in waters off northern Europe and Iceland, and in the northwest Atlantic, off eastern Canada (Murrel & Fried, 2007). According to Young (1972), *Terranova decipiens* (=*Pseudoterranova*) has been reported from at least eighteen species of Pinnipedia, five species of Cetacea and one species of Mustelidae.

The larvae are easy to identify due to its large size and its red colour (Osanz Mur, 2001). *P. decipiens* can be considered cosmopolitan specie that reaches maturity in seals and infection occurs naturally in marine invertebrates that act as intermediate hosts e.g. copepods (Young, 1972; Bush et al., 2001; Leger, 2007). Also, it has the ability to complete its benthic life cycle even under cold temperatures from the Antarctic (Osanz Mur, 2001). Furthermore, it shows a low degree of specificity because it has been found in many fish species (Murrel & Fried, 2007).

Genus Contracaecum

The Contracaecum larvae measures between 4 and 16mm. It has as definitive hosts piscivorous birds and marine mammals (Young, 1972; Bush et al., 2001; Leger, 2007). The evolution of the parasite from birds to marine mammals increases its potential for dissemination to infect other species, including humans (Osanz Mur, 2001).

Contracaecum species differ from other Anisakid species that the L3 larvae infects directly small fish species (Osanz Mur, 2001). One of the most studied species is *Contracaecum osculatum*, which has gray seals as definitive host (Murriel & Fried, 2007).

1.2.2 Pathology of Anisakis in marine mammals

One of the earliest records of pathology in marine mammals caused by Anisakis was apparently that of Murie (1868), who described ulceration of the fundic stomach of the walrus caused by *Anisakis simplex*, which he believed led to the death of the host (Smith & Wootten, 1978). Parasites of marine fish have been more extensively studied than parasites of any other marine host group (Rhode, 2002).

Early studies found inflammatory reactions and ulcerations caused by Anisakis in several dolphin species, including bottlenose dolphin, harbour porpoise and short-beaked common dolphin (Dailey & Browell, 1972; Smith & Wootten, 1978). They also observed that normally adult Anisakis are only superficially attached to the stomach wall and therefore no ulcerations are caused.

Intestinal parasites inhibit the digestive activity of the hosts and indirectly inhibit vitamin and blood sugar metabolism and growth (Rhode, 1993; Berta, 2006). Nonetheless, infections are generally not serious to the host (Geraci & Aubin, 1987). Several studies have agreed that infections are not the primary cost of death in stranded marine mammals; however it could be associated (Baker & Martin, 1992). Furthermore, Baker & Martin (1992) study on causes of mortality in 41 stranded harbour porpoises from British waters found the presence of *Anisakis simplex* in the stomach of 18 of the 41 stranded animals. Gastric ulcers were found in 46 per cent of the animals as a secondary lesion. In addition, they concluded that the presence of the parasites was not the cause of the stranding and the consequent death of the individuals, so they listed as a non-fatal condition.

Anisakiasis

The role of marine mammals in transmitting the parasites to commercially exploited fish stocks is a public health issue (Geraci & Aubin, 1987). The infection of man by marine nematodes of the family Anisakidae is called Anisakiasis (**Fig. 3**). Several species of Anisakis (mainly *Anisakis simplex*) and Pseudoterranova (mainly *Pseudoterranova decipiens*) have been confirmed as agents of human anisakiasis (Rhode, 1993; Murrel & Fried, 2007).

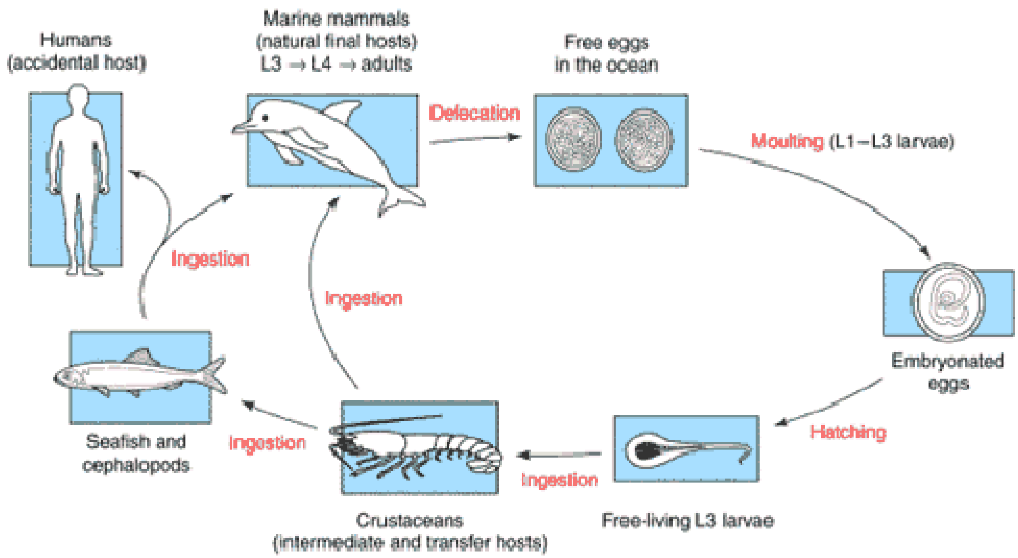

Figure 3. Anisakiasis life cycle (extracted from www.iidmm.uct.ac.za/alopata/research.htm).

Anisakiasis occurs when people are infected with larval stages of anisakine nematodes due to the ingestion of raw fish, insufficiently cooked or smoked fish, marinated or salted fish. It reduces the quality of the flesh and can have an impact on human health (Noguera *et al.*, 2009). Therefore, Anisakis is a serious zoonotic disease, and there has been a dramatic increase in its reported prevalence throughout the world in the last two decades (Rhode, 2002; Murrel & Fried, 2007).

The measures for prevention of Anisakiasis are either to freeze the fish at -20ºC for a minimum of five days or smoke the fish at temperatures above 65ºC; both measures will kill the larvae and thus the fish will be suitable for consumption (Osanz Mur, 2001).

1.3 Harbour porpoise, *Phocoena phocoena*, Linnaeus (1758)

1.3.1. General biology and current status

Harbour porpoise belongs to the suborder Odontoceti, which is mainly characterized by the presence of teeth and the genus Phocoena, which was named by Linnaeus 1758 (Carwardine, 1998).

Harbour porpoise (**Fig. 4**) is one of the smallest cetaceans in the ocean (Cawardine, 1995; Walton, 1997). Harbour porpoise is quite difficult to observe because it does not approach to vessels (Cawardine, 1995; Reynolds & Rommel, 1999). Both sexes grow up to 1.4 and 1.9m, though males are smaller than females (Isojunno, 2006). Furthermore, females are heavier than males, with a maximum weight of 76kg. The colour of the flippers, dorsal fin, tail fin and back is dark grey. The sides are a slightly grey colour (Reynolds & Rommel, 1999). The underside is much whiter, though there are usually grey stripes running along the throat from the underside of their body (Cawardine, 1995; Mann, 2000). Sexual maturity is believed to arrive at 3 to 4 years of age (Berta *et al*., 2006). They are short-lived animals (Walton, 1997).

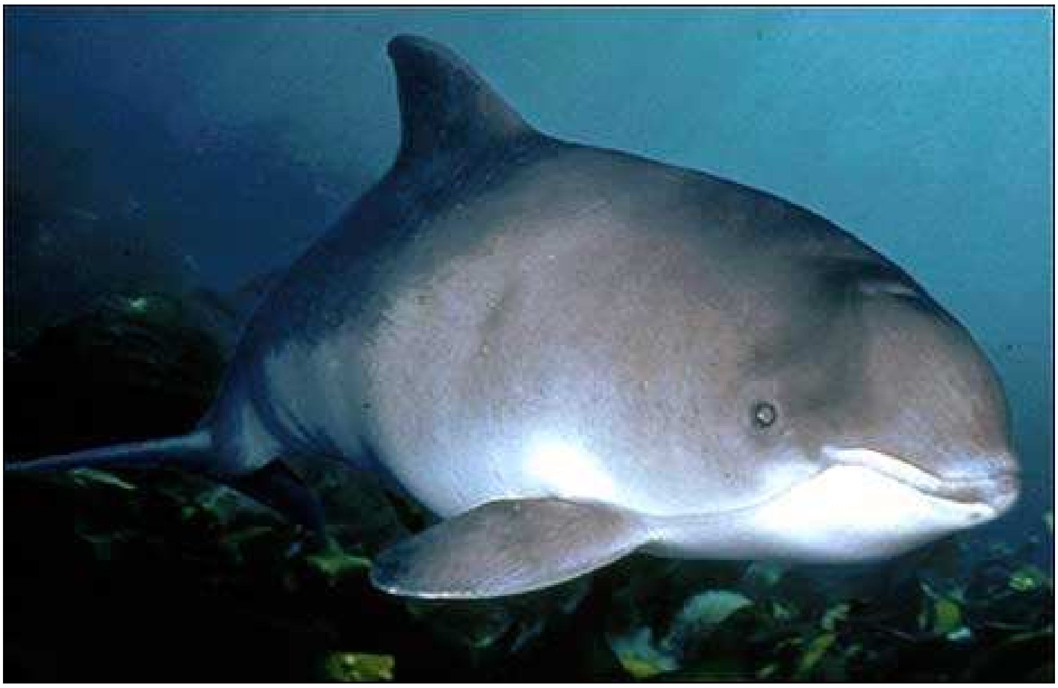

Figure 4. Harbour porpoise (www.bbc.co.uk)

Harbour porpoises eat a wide variety of fish and cephalopods, and the main prey items vary regionally (Cawardine, 1995; Mann, 2000; Hammond *et al*., 2008). They feed mostly on small schooling fish in the water column and near the bottom (Isojunno, 2006), e.g. herring, capelin and sprat (Reynolds & Rommel, 1999).

According to the IUCN Red List of Threatened Species, this specie is classified as "of least concern" (Hammond *et al*., 2008).However, they are highly susceptible to incidental capture and death by asphyxiation in fishing nets (Tregenza *et al*., 1997; Walton, 1997).

1.3.2. Distribution

Harbour porpoise distribution is close to coastal areas or river estuaries (Cawardine, 1995; Walton, 1997). It is largely limited to continental shelf waters (Reynolds & Rommel, 1999).They may normally be seen alone, in pairs or in small groups of 6 to 10 individuals (Isojunno, 2006). However, groups of 50 to 100 have been reported (Mann, 2000). They are found in cold temperate to sub-polar waters of the Northern Hemisphere, mainly between 11 to 14ºC (**Fig. 5**), (Cawardine, 1995; Isojunno, 2006).

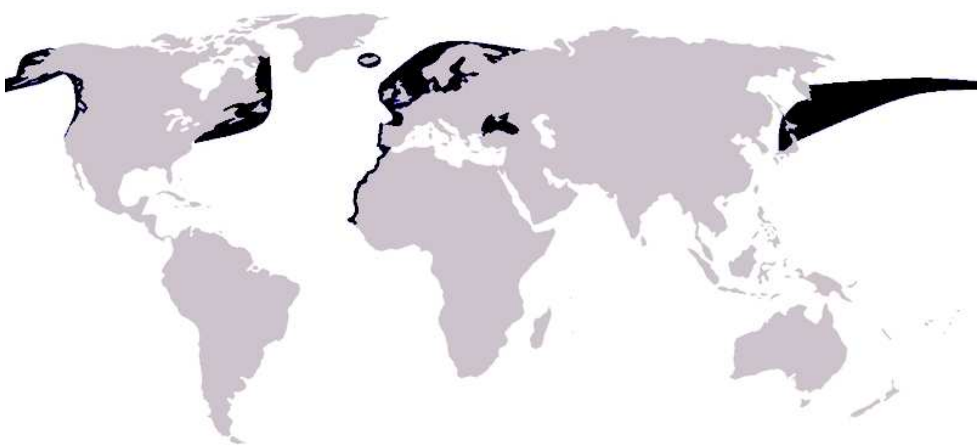

Figure 5. Harbour porpoise world distribution map (modified from www.wikipedia.org)

They are common and widely distributed in Northern Europe from Iceland to northern Norway south to southern Ireland and southwest England. Rare in the Baltic Sea, North Sea, Bay of Biscay, Iberian Peninsula and Mediterranean Sea (Hammond *et al*., 2008). Moreover, they are abundant also in North-east Scotland, western and southern Ireland and off the coast of South-west England (Isojunno, 2006).

According to Walton (1997) there has been a markedly declined of its population in areas such as southern North Sea, the Baltic and the English Channel. Despite the evident declines in the southern North Sea, English Channel and the Irish Sea in the 1960s-1980s, the population of harbour porpoise in the Celtic, North and southern Baltic seas is estimated at more than 340,000 (**Fig. 6**). It still remains the most common and widespread cetacean in British waters and widely distributed over the north and central North Sea (Isojunno, 2006).

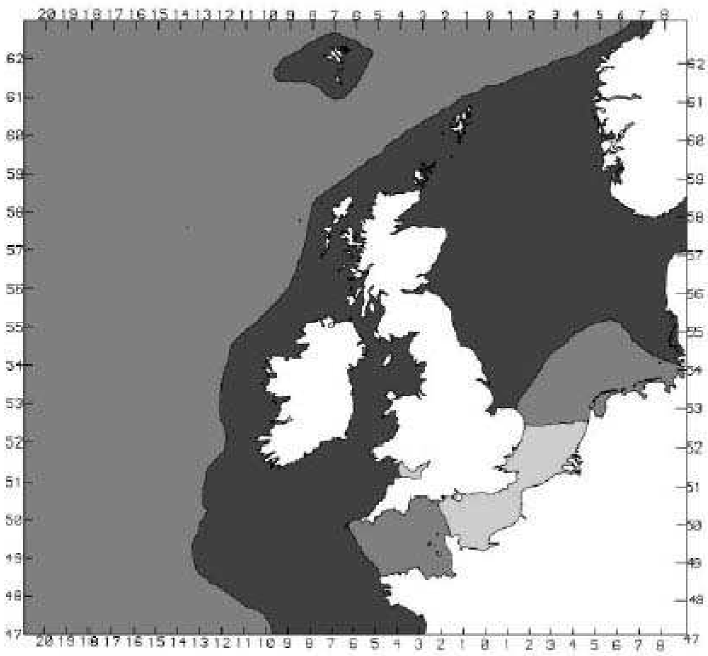

Figure 6. Harbour porpoise distribution around the British Isles. Dark grey: regular occurrence; medium grey: occasional occurrence; light grey: absent/casual (www.cms.int)

1.4 Bottlenose dolphin, *Tursiops truncatus*, Montagu (1821)

1.4.1. General biology and current status

Bottlenose dolphin, *Tursiops truncatus*, belongs to the suborder Odontoceti and the genus Tursiops named by Montagu in 1821 (Cawardine, 1995). They are the most common cetaceans in aquaria due to their curiosity towards humans (Bartolomé & Vega, 2000; Mann, 2000).

Bottlenose dolphins (**Fig. 7**) reach a length of 2.5 to 3m (Cawardine, 1995; Bartolomé & Vega, 2000). Males are 10 to 20cm longer than females (Dailey & Browell, 1972). They weight up between 150 and 650kg ().They vary in colour from blueish steel gray or slate grey to charcoal with noticeably lighter ventral pigmentation (Cawardine, 1995; Bartolomé & Vega, 2000; Berta *et al*., 2006). Larger body size is generally associated with colder water temperatures (Mann, 2000). They are long-lived; females may live for more than fifty years and males for more than forty (Dailey & Browell, 1972). Females reach sexual maturity between age 5 and 13 and males slightly later between 9 and 14 (Berta *et al*., 2006).

Figure 7. Bottlenose dolphin (www.seawatchfoundation.org.uk)

They typically live in groups of 15 dolphins, but group sizes varies from solitary up to groups of over 100 or even occasionally over 1000 animals (Mann, 2000). Furthermore, they are commonly associated with many other cetaceans, including both large whales and other dolphin species (Hammond *et al*., 2008).

They feed on a wide variety of fish, as well as some cephalopods e.g. squid and octopus (Dailey & Browell, 1972; Bartolomé & Vega, 2000; Ingram & Rogan, 2002), and occasionally shrimp and small rays and sharks. It is unclear whether buried prey are detected with echolocation or visually by some surface disturbance in the sand, although intense echolocation is typically heard during these feeding episodes.

According to the IUCN Red List of Threatened Species, this specie is classified as "of least concern" (Hammond *et al*., 2008). In 2006, the Mediterranean subpopulation of bottlenose dolphins was qualified as "vulnerable" according to the IUCN Red List Criteria (Bearzi *et al*., 2008). According to the IUCN Red List Criteria (2001) "a taxon is vulnerable when the best available evidence indicates, a reduction in population size or small geographic range or a population size estimate to fewer than 10,000 mature individuals and it is therefore considered to be facing a high risk of extinction in the wild".

1.4.2. Distribution

Bottlenose dolphins are found in temperate and tropical waters worldwide (**Fig. 8**); in inshore, coastal, shelf and oceanic waters (Bartolomé & Vega, 2000; Ingram & Rogan, 2002; Hammond *et al*., 2008). They even are known to travel up rivers. Its accessibility in near shore waters has also made them the best-studied cetacean (Mann, 2000; Ingram & Rogan, 2002). They are the most common species along the Atlantic coast of America and are frequently seen on the European Atlantic coasts (Dailey & Browell, 1972).

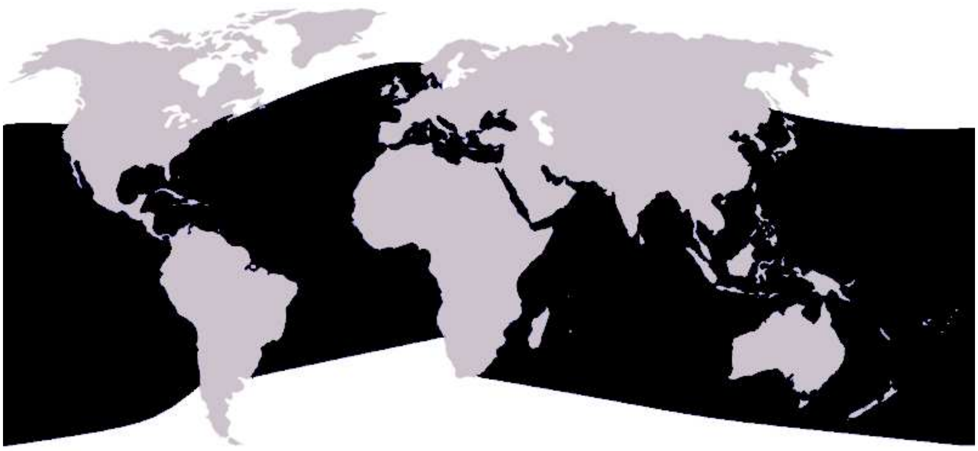

Figure 8. Bottlenose dolphin world distribution (modified from www.wikipedia.org).

In the Atlantic it occurs north to the Gulf of Mexico, the Azores, the British Isles, the Faroe Islands, and the Baltic Sea including the Gulf of Finland, the Mediterranean and Black Seas. In the Pacific it ranges north to the Gulf of Chihli, East China Sea, Hawaii and Monterey Bay in California. In the southern Hemisphere it occurs south to Golfo San Matias in Argentina, south western Indian Ocean, the southern coast of Australia including Tasmania, South Island in New Zealand and Chile (Hammond *et al*., 2008). In Ireland they can be seen in all coasts, the resident population in the Shannon estuary has been estimated in 130 dolphins. (**Fig. 9**).

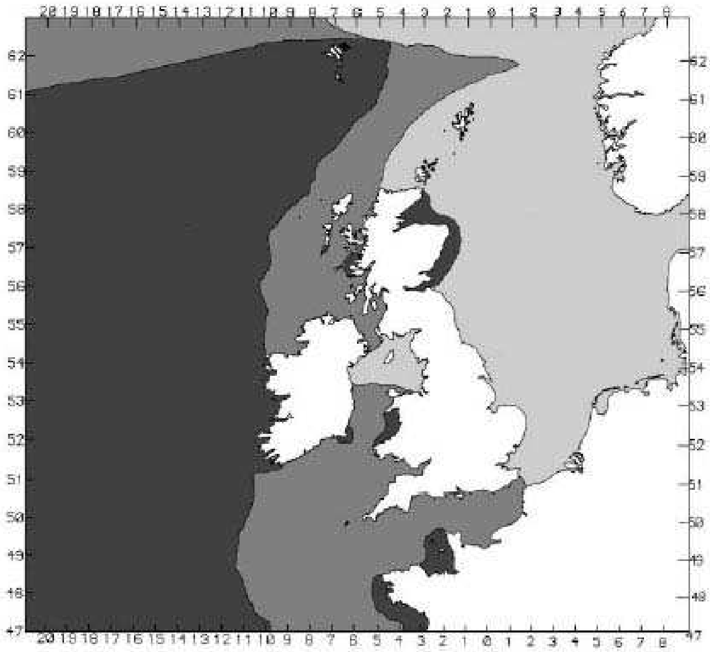

Figure 9. Bottlenose dolphin distribution around the British Isles. Dark grey: regular occurrence; medium grey: occasional occurrence; light grey: absent/casual (www.cms.int)

1.5 Short-beaked common dolphin, *Delphinus delphis*, Linnaeus (1758)

1.5.1. General biology and current status

The short-beaked common dolphin, *Delphinus delphis*, belongs to the suborder Odontoceti and the genus Delphinus, which was named by Linnaeus in 1758 (Dailey & Browell, 1972; Carwardine, 1998). Delphinids are the most diverse of the cetacean families and include 17 genera and 36 extant species of dolphins, killer whales, and pilot whales (Carwardine, 1998; Berta *et al.*, 2006).

The short-beaked common dolphin (**Fig. 10**) is a small cetacean species, reaching lengths of <2.15m (Dailey& Browell, 1972; Carwardine, 1998; Scullion, 2004; Bush, 2006) and weighing up to 200 Kg (Scullion, 2004). Males are generally 10 to 20cm larger than females (Dailey & Browell, 1972; Carwardine, 1998). Females become sexually mature between 5-12 years of age, with males maturing slightly earlier (between 3-12 years of age), (Dailey & Browell, 1972). Neumann & Orams (2005) suggested that they reach sexual maturity around six years of age. Individuals are assumed to live 25 to 30 years (Dailey & Browell, 1972). The body colour of short-beaked common dolphins is distinctive. The dorsal surface is black, the ventral is white, and the sides are ochre and gray (Dailey & Browell, 1972; Carwardine, 1998; Scullion, 2004).

Figure 10. Short-beaked common dolphin (www.nmfs.noaa.gov)

Common dolphins are generally considered to be pelagic, with most groups occurring over the continental shelf and beyond (Neumann & Orams, 2005). They are opportunistic feeders, thus their diet can vary according to geographical locations and seasonal fluctuations in prey distribution and abundance (Bearzi *et al*., 2003; Neumann & Orams, 2005; Bush, 2006). Mainly they feed on pelagic fish such as anchovy, mackerel, herring, sardine and sprat (Santos *et al*., 2004; Scullion, 2004; Neumann & Orams, 2005), although they can also feed on squid (Bearzi *et al*., 2003; Scullion, 2004; Bush, 2006).

According to the IUCN Red List of Threatened Species, this specie is classified as "of least concern" (Hammond *et al*., 2008). However, in 2003 the Mediterranean subpopulation was listed as endangered based on criterion A2, which refers to a 50% reduction in abundance over the last 30 years, the cause of which "may not have ceased or may not be understood or may not be reversible" (Bearzi *et al*., 2003). Over the last 50 years common dolphins have been replaced by striped dolphins in the Mediterranean (Viale, 1994).

1.5.2. Distribution

Common dolphins (Delphinus spp., family Delphinidae) are considered to be of high abundance with a worldwide distribution (Oswald *et al*., 2003; Santos *et al*., 2004; Neumann & Orams, 2005). They occur frequently in the Atlantic Ocean and its adjacent seas (**Fig. 11**). They are also found in the Indian Ocean and in both the South and North Pacific but they do not migrate into the cold waters (Dailey & Browell, 1972). In general, they occur where the sea surface temperature (SST) oscillates between 10- 28ºC, therefore limiting their distribution to the north and south (Carwardine, 1998).

Figure 11. Common dolphin World distribution map (modified from www.wikipedia.org)

Common dolphins generally remain localized though some populations have been recorded migrating seasonally (Carwardine, 1998). They form large groups, sometimes numbering in the thousands (Neumann & Orams, 2005; Scullion, 2004). Bearzi *et al*. (2003) recorded groups of 50-70 animals in the Mediterranean, with aggregations of 100-600 animals occasionally.

In Ireland, common dolphins can be regularly found in the southern Irish sea and the Celtic Deep area, in the western approaches to the English Channel, around the Inner Hebrides and west of Ireland (**Fig. 12**), (Ansmann, 2005).

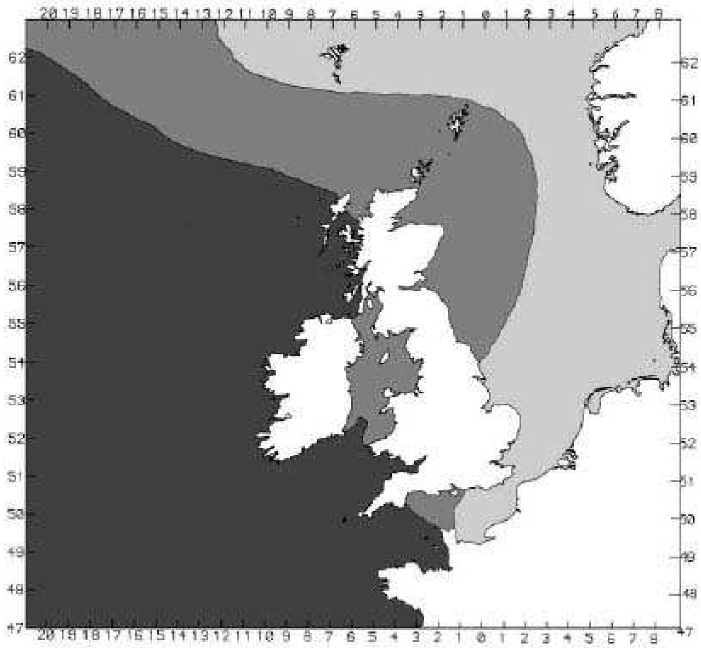

Figure 12. Short-beaked common dolphin distribution around the British Isles. Dark grey: regular occurrence; medium grey: occasional occurrence; light grey: absent/casual (www.cms.int).

1.6 Objectives

The main objective of this study is to collect and compile all the information available out there regarding parasites of the Fm. Anisakidae and their definitive hosts.

Furthermore, two secondary aims are proposed. The first secondary aim is to relate the presence of cetacean species with the presence of parasites of the Fm. Anisakidae and the second one is to determine whether this greater number of cetaceans relates to a greater level of parasitism.

2. Material and Methods

The materials and methods used are the collection and review of scientific articles and books in reference to our subject of study and a summary of all the information gathered. In addition, a questionnaire (**Fig. 14**) was conducted and sent to several experts on the field in order to get specific knowledge from Irish waters.

Moreover, data from previous published and non-published (undergraduate students under supervision of Dr. Emer Rogan, UCC) studies (see **Appendix III**) and the cetaceans' strandings and sightings database (see **Appendix II**) from the Irish and Whale Dolphin Group website (**Fig. 13**) were used for making the tables and graphs.

Figure 13. Irish Whale and Dolphin Group website (www.iwdg.ie)

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Figure 14. Questionnaire.

Universitat de Girona

GMIT
GALWAY-MAYO INSTITUTE OF TECHNOLOGY
INSTITIÚID TEICNEOLAÍOCHTA NA GAILLIMHE-MAIGH EO

My name is Lídia Sarrà Alarcón and I am a Master of Science student at University of Girona (Spain). I have got an Erasmus scholarship with GMIT for the next three months.

The idea of my research is to analyze if there is a relation between the presence/absence of cetacean's population with the increase of parasites in fish populations.

Contact details: u1903397@correu.udg.edu *or* lidia_sarra_alarcon@hotmail.com

Contact at UdG: **Dr. Margarida Casadevall** (margarida.casadevall@udg.edu)

Contact at GMIT: **Dr. Pauline King** (Pauline.King@gmit.ie)

I would appreciate if you can fill up the following questionnaire.

QUESTIONNAIRE

Name: ____ **Date:** _________________

Institution/Research Group: ____

1) **Which species are most frequently found during strandings? Write numbers from 1 to 4. (Note: 1 is the most frequent and 4 is the less frequent).**

   a) *Tursiops truncatus* ☐
   b) *Delphinus delphis* ☐
   c) *Stenella coeruleoalba* ☐
   d) *Ziphius cavirostris* ☐
   e) Others: __________________________

2) **How often do they strand?**

   ____

   ____

3) **Which months of the year have more strandings? Why?**

   ____

   ____

Universitat de Girona

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4) Is there a place where they strand more often? Where?

____

____

5) How many years of data have you collected?

a) 1 to 5 years.
b) 5 to 10 years.
c) More than 10 years.

6) Do you do necropsies on the stranded cetaceans?

a) Yes, we do.
b) No, we don't. (Continue to question 10)
c) No, but we know someone that does.
Name and contact details: ___________________________
(Continue to question 10)

7) Have you seen any parasite (especially from the *Anisakidae* family) during those necropsies?

a) Yes, we have.
b) No, we haven't (Continue to question 10)
c) Others: ____________________________
(Continue to question 9)

8) Have you analyzed any parasite found during those necropsies? Do you know someone that does?

____

____

9) How many parasites have you seen in one cetacean?

a) 1 to 10.
b) 10 to 50.
c) More than 50.

10) Do you know any other researcher that has recollected data from strandings, necropsies or parasite infections in cetacean?

____

____

3. Results

Cetacean abundance estimates

Based on the information taken from the Questionnaire completed by Dr. Emer Rogan from UCC (see **Appendix I**), the following small cetacean species are within the most stranded around Ireland and the ones that have been reported to carry parasites from the Fm. Anisakidae; Harbour porpoise (*Phocoena phocoena*), short-beaked Common dolphin (*Delphinus delphis*) and Bottlenose dolphin (*Tursiops truncatus*). Also with the data information recollected by the Irish Whale and Dolphin Group (see **Appendix II**) and many volunteers around Ireland (available at www.iwdg.ie) the following graphs were made comparing strandings versus sightings over the last 20 years in Irish waters, to get a raw estimate of the abundance of these species of cetaceans around Ireland. In order to avoid overestimate, I have considered each stranding and sightings as one without considering the number of individuals observed. That means that in strandings or in sightings of more than one individual, I have considered that they account just for one.

Over the last 20 years, a total number of 1593 strandings and 14035 sightings have occurred in Irish waters. Of those 1593 strandings harbour porpoise accounted for 456 (27.8%), short-beaked common dolphin made up for 331 (20.7%) and bottlenose dolphin for 82 (5.1%). Of those 14035 sightings harbour porpoise made up for 4912 (35%), short-beaked common dolphin accounted for 2245 (16%) and bottlenose dolphin for 1874 (13.4%). Note that this number is an estimate one because there may still be some cases where neither strandings nor sightings are reported.

Harbour porpoise is clearly the most stranded cetacean in Ireland over the past 20 years. The second most common stranded is the short-beaked common dolphin. Bottlenose dolphin is one of the less stranded cetaceans (**Fig. 15**). However, the number of strandings has dramatically increased for the last 10 years approximately. During the 90s, the total number of cetacean stranded per specie was comprised between two and 15 strandings, whereas on the past 10 years, the total number reaches 45. Harbour porpoise has always been the most stranded specie except for years 1992, 1994, 1998 and 2006 where there were more strandings of short-beaked common dolphin. On the other hand, during 1990, 1994, 1995, 1996 and 1997 there were no strandings of bottlenose dolphins. Since 2004, there has been a slightly increase in the total number of strandings of bottlenose dolphins, reaching its peak in 2009 with 12 strandings.

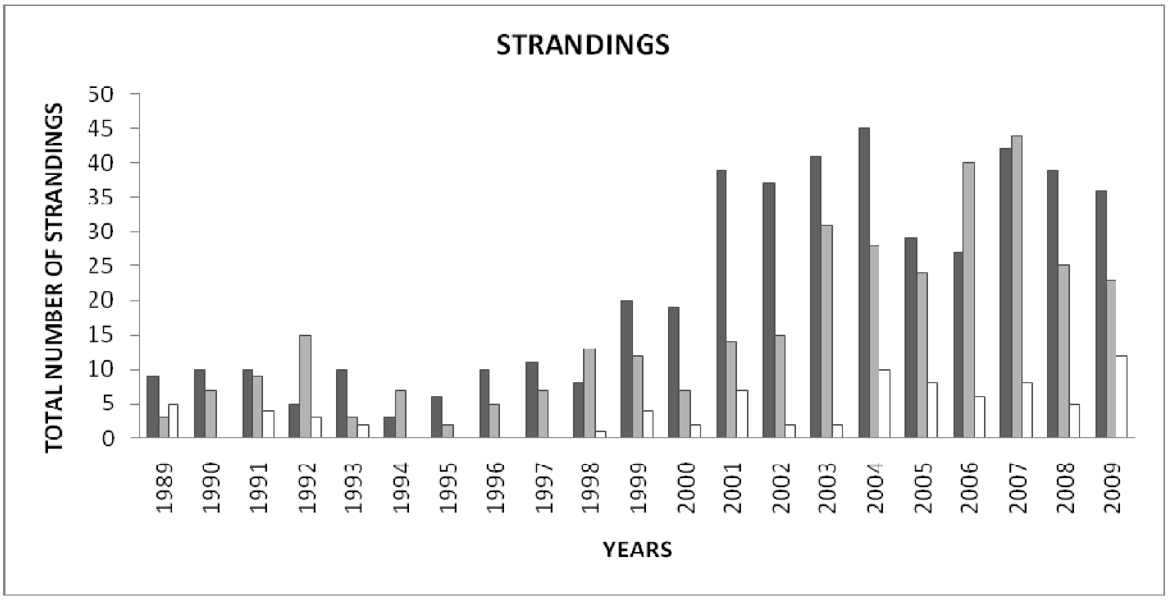

Figure 15. Total number of strandings of the three most common small cetacean species over the last twenty years in Ireland. Harbour porpoise (black), short-beaked common dolphin (grey) and bottlenose dolphin (white).

The same pattern observed with the strandings is seen with the sightings. Again, harbour porpoise is the most seen cetacean, especially over the last nine years with its peak in 2008 with over 600 sightings (**Fig. 16**). Short-beaked common dolphin is the second specie most seen and bottlenose dolphin being the third one. Between 1989 and 1992 the sightings were minimal (almost non-existent) for the three species studied then, from 1993 to 1996 there was an increase with almost 200 sightings of harbour porpoise. After 1996 there was a period of few sightings till 2001 where the total number of sightings dramatically increased for all the species but most importantly for harbour porpoise. Short-beaked and bottlenose dolphins' sightings remained constant or with slights variations in the past nine years. In 1997 there were more sightings of short-beaked common dolphin than harbour porpoise.

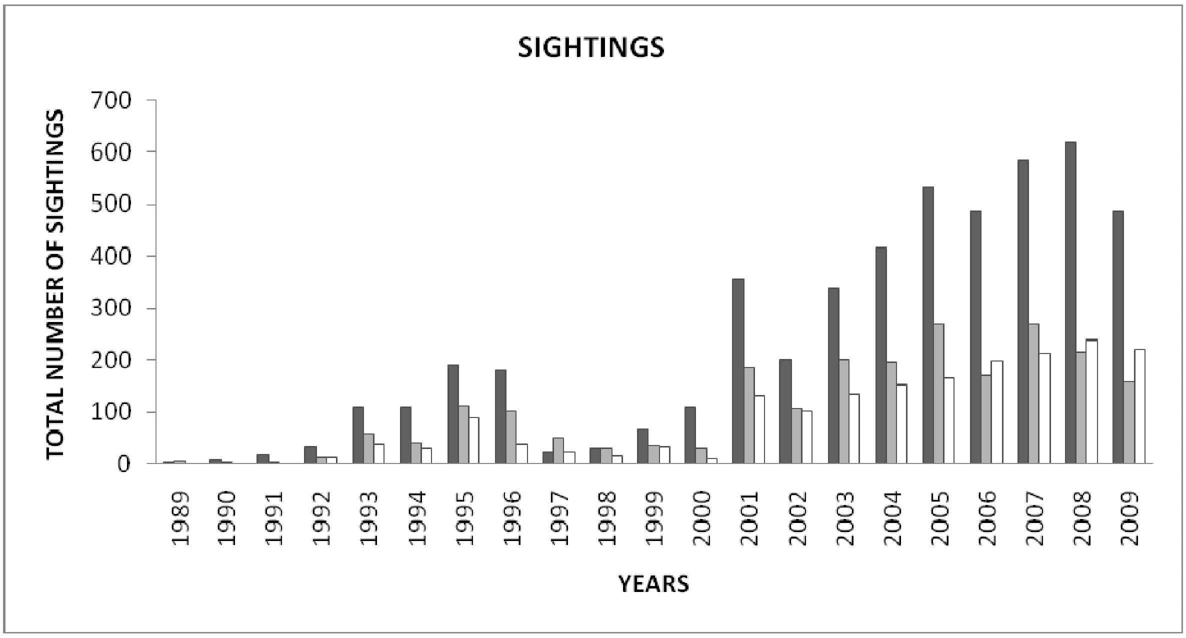

Figure 16. Total number of sightings of the three most common small cetacean species over the last twenty years in Ireland. Harbour porpoise (black), short-beaked common dolphin (grey) and bottlenose dolphin (white).

A mean comparison of the seasonal distribution of strandings and sightings over the past twenty years for each species is shown below (**Fig. 17)**. Harbour porpoise are shown to have its strandings peaks during the first months of the year (mainly January, February and March) with approximately three strandings per month, whereas the rest of the year the strandings remained low, approximately one. On the other hand, the sightings were more frequent during the summer months (especially June, July, August and September), oscillating between 26 and 40 sightings approximately per month, whilst the rest of the year remained below 17 sightings. Short-beaked common dolphin showed a slightly different distribution throughout the year. Even though, it can be observed the same peak of strandings during the winter months (January, February and March) and the rest of the year remained constant, there was a highly difference with the sightings distribution. According to the graph, short-beaked common dolphin populations are mostly seen in August where its peak reached over 25 sightings approximately. The months of July, September and October, all three had a mean over 11 approximately, whereas the rest of the year the sightings remained below 8. Bottlenose dolphin populations had its stranding peak in July with approximately 0.67 strandings and February and May had the lowest recordings with a mean of 0.019 strandings each month. Bottlenose dolphin sightings showed a bell distribution with its peak during late spring and summer months (being especially high during June, July and August with a mean over 14.5) and its lowest point during winter months, below six.

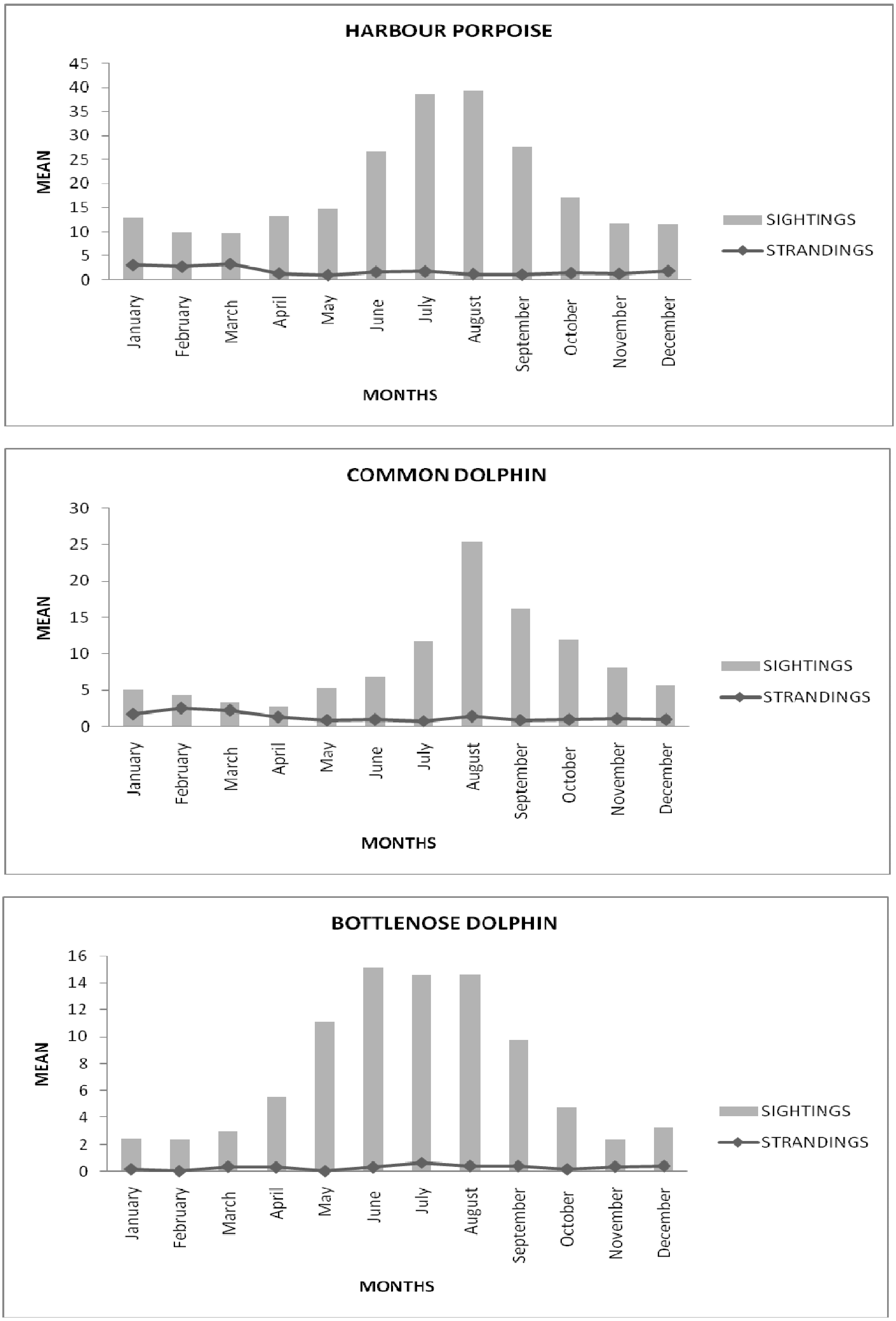

Figure 17. Monthly means comparison of strandings versus sightings for harbour porpoise (top), short-beaked common dolphin (middle) and bottlenose dolphin (bottom).

Levels of parasitism

Information on various scientific papers had been gathered to build a Host-Parasite list (**Table 1**) in relation to the three species of small cetaceans of our study.

Anisakis simplex was found common in all three cetacean species observed in this study. *Contracaecum sp*. and *Pseudoterranova sp*. were recorded from bottlenose dolphin in several studies conducted in waters all over the world. Other studies conducted on harbour porpoise and short-beaked common dolphin could not identify the nematode at a species level and they were only described as Anisakis spp.

Table 1. Host-Parasite list.

Cetacean specie	**Nematoda specie**	**Reference**
Harbour porpoise	*Anisakis simplex*	Dailey & Browell, 1972
(*Phocoena phocoena*)		Young, 1972
	Anisakis spp.	O'Leary, 1996 (UCC)
		Hickey, 2006 (UCC)
Short-beaked common dolphin	*Anisakis simplex*	Dailey & Browell, 1972
(*Delphinus delphis*)		Young, 1972
		Abollo *et al*., 1998
		Gibson *et al*., 1998
		Colom-Llavina, 2005
		Berón-Vera *et al*., 2007
	Anisakis spp.	Nahadajah, 1995 (UCC)
Bottlenose dolphin	*Anisakis simplex*	Dailey & Browell, 1972
(*Tursiops truncatus*)	*Contracaecum sp.*	Abollo *et al*., 1998
		Gibson *et al*., 1998
		Sánchez *et al*., 2002
		Colom-Llavina, 2005
	Pseudoterranova sp.	Abollo *et al*., 1998
		Gibson *et al*., 1998
		Sánchez *et al*., 2002
		Colom-Llavina, 2005

Several studies conducted by undergraduate students from University of College Cork (UCC) under the supervision of Dr. Emer Rogan obtained the results shown in **Table 2** (see **Appendix III**).

The presence of gastric nematode parasites from the Fm. Anisakidae were studied in two of the most common species of small cetaceans that strand or are accidentally by-catch by the fisheries industry around Ireland, but mainly in the south coast; Harbour porpoise (*Phocoena phocoena*) and short-beaked common dolphin (*Delphinus delphis*). The two projects conducted in harbour porpoise were done in 1996 and 2006 and the project in 1995 with short-beaked common dolphin. The number of Anisakis spp. varied for each study, specie and season. O'Leary (1996) found 26 Anisakis spp. in harbour porpoise, with a prevalence of 46%. Hickey (2006) found 12 Anisakis spp. in harbour porpoise obtaining a prevalence of 100%. Nahadajah (1995) found 25 Anisakis spp. in short-beaked common dolphin with a prevalence of 68%.

Table 2. Levels of parasitism in small cetaceans in Irish waters.

Nematode Sp.	n	Prevalence	Host species	Reference
Anisakis spp.	12	100%	Harbour porpoise	Hickey, 2006 (UCC)*
	26	46%	Harbour porpoise	O'Leary, 1996 (UCC)*
	25	68%	Common dolphin	Nahadajah, 1995 (UCC)*

*Information obtained from personal conversation with Dr. Emer Rogan from UCC.

4. Discussion

Cetacean abundance estimates

Harbour porpoise is clearly the most stranded small cetacean in Irish waters (see **Appendix I**). Harbour porpoise population has lately experienced a widespread decline all around Europe. It may be absent or scarce in the coast of the countries bordering the southern North Sea, including some British localities bordering upon the northern North Sea (Evans *et al*., 1996).

Berrow & Rogan (1997) review on strandings records showed that harbour porpoise accounted for 27% of the strandings, being the most frequently reported, followed by Common dolphin (16%) and Pilot whales (15%). Over the last 20 years, harbour porpoise is the most stranded cetacean in Ireland with a proportion of 27.8% (see **Appendix II**). Moreover, in 1992, 1994, 1998 and 2006 the number of strandings showed a slightly decreased due to an increase of short-beaked common dolphin strandings. Concretely, in 1992 there was a mass stranding of common dolphins possibly attributed to fisheries interactions (Berrow & Rogan, 1997), which may explain the highest number of stranding reports on common dolphins.

The second most common stranded cetacean is the short-beaked common dolphin, *Delphinus delphis*, with a proportion of 20.7% (see **Appendix II**). In particular, short-beaked common dolphin's strandings showed a dramatically increase since 2003, having its maximum peak in 2007 with 44 events. These results could possibly indicate a decrease in the Irish sub-population, as experienced by the Mediterranean sub-population (Viale, 1994). Besides, there had been misidentifications regarding to common dolphin strandings due to its resemblance with striped dolphins, which have lead to its wrong identification.

Bottlenose dolphins are one of the less stranded cetaceans in Irish waters. In this study they accounted for 5.1% (see **Appendix II**). According to Berrow & Rogan (1997), during the past century only 19 strandings were reported with nine being during the 1990s. Thus, this clearly shows an increase of bottlenose dolphin strandings. Also, during 1990, 1994, 1995, 1996 and 1997 there were no strandings reported for bottlenose dolphins. In 2009 they reached its maximum peak to date with 12 strandings.

Stranding events occur throughout all the year. Harbour porpoises showed an increase during autumn and winter (September to March), which has been associated with fisheries, especially the herring fishery (Berrow & Rogan, 1997). As well, our results indicated that short-beaked common dolphins have its peak during August and September, although results from previous reviews reported that their peak occur during January and February (Berrow & Rogan, 1997). Those differences may be due to the sampling period. Berrow & Rogan (1997) analyzed all the strandings occurred from 1901 to 1995, on the contrary, this study only focuses on the analysis of the past 20 years (from 1989 to 2009) and therefore some oversampling may occur. In addition, bottlenose dolphins strand throughout all the year but with greater seasonal trend during spring and summer (May to September).

Furthermore, the majority of the stranding events occur along the south coast and western seaboard (Berrow & Rogan, 1997). Still nowadays, there are stranding events that are not reported, so this is only an estimate. Moreover, the differences in the number of reported standing's may also be due to a greater or lesser effort carried out by the observer (Berrow & Rogan, 1997).

Regarding the sightings, the results follow the same pattern as the strandings. Harbour porpoise made up for 35% of the sightings, followed by short-beaked common dolphin (16%) and bottlenose dolphin accounted for 13.4% (see **Appendix II**). Also, note that this number is an estimate one because there may still be some cases where neither strandings nor sightings are reported. Between 1989 and 1992 there were really few sightings for the three species which could be due to weather conditions or it could also be due to a lesser amount of observers. The same thing happened from 1997 to 2000. There were strandings reported on those years, so we know that the animals were there. Also, the populations could have gone further apart from the coastal areas, which make it difficult to sight them. The strandings could be due to entanglement with fisheries nets and as a result they could have ended wash up dead in the coasts. Then, from 1993 to 1996 there was a significant increase of approximately 200 sightings of harbour porpoise. In addition, in 1997 there were more sightings of short-beaked common dolphin than harbour porpoise. All these could mean an increase of scientific surveys and observer effort. Also in 2001 the number of sightings dramatically increased for all three species but most importantly for harbour porpoise. This could be because of the habitat preferences, harbour porpoises are mostly coastal animals and therefore it is not strange to have more reported sightings than for the other species. On the contrary, short-beaked common dolphins and bottlenose dolphins prefer offshore waters.

Comparing the means for all three species, it can be observed that harbour porpoise has its stranding peak during January, February and March, whereas the sightings occur mostly during summer months (June, July, August and September). Also, short-beaked common dolphin presented the same stranding peak than harbour porpoise. However, August alone was the month with more sightings, whereas the rest of the year the sightings remained low. Bottlenose dolphin showed a stranding peak in July. On the contrary, bottlenose dolphin sightings showed a bell distribution with its peak during late spring and summer months (especially June, July and August). This can be due to several factors such as weather conditions, which makes it difficult to sight them. Another factor is the number of surveys conducted and the areas where they are undertaken. Also, the observer effort, volunteers may not report neither all the strandings nor all the sightings.

Levels of parasitism

The population structure of anisakid nematodes has been more frequently studied in intermediate fish hosts than in definitive hosts species. Prevalence and burdens of anisakids in definitive hosts vary widely with host species, geographic location, and season (Murrel & Fried, 2007). Smith & Wootten (1978) found that in the Northern North Sea there was a large increase in the abundance of *A. simplex* in the musculature of whiting in the late 1970s; however, from 1960-63 the prevalence was less than 1.5% in over 9000 fish examined, but in 1971-74 the prevalence increased again and made up for 60% or more.

Internal parasites of marine mammals tend to be less specialized to the marine environment than external parasites. While their location and pathogenicity may be more predictable, their life cycle are generally obscure (Geraci & Aubin, 1987). Some records have estimated more than 20,000 worms per host, this intensity of infection is generally positively related to host age and size (Murrel & Fried, 2007).

Baker & Martin (1992) conducted 49 post-mortem exams on harbour porpoises. The commonest causes of death were entanglement in fishing gear, and parasitic and bacterial pneumonia. Among the non-fatal conditions parasitoses of various organs were common and there was a very wide variety of other condition. In total 295 diseases and other lesions were found. Rogan et al. (2001) carried out post-mortem exams on 29 harbour porpoises, 11 of which presented nematode parasites, identified as *A. simplex*, giving a prevalence of 38%. Again, they were not directly responsible for mortality in any of the individuals examined.

Adult worms in the *Anisakis simplex* complex appear to be associated principally with oceanic dolphins and porpoises, such as harbour porpoises (*Phocoena phocoena*), (Dailey & Browell, 1972; Young, 1972), short-beaked common dolphins (*Delphinus delphis*), (Dailey & Browell, 1972; Young, 1972; Abollo *et al*., 1998; Gibson *et al*., 1998; Colom-Llavina, 2005; Berón-Vera et al., 2007), bottle-nosed dolphins (*Tursiops truncatus*), (Dailey & Browell, 1972), among others (Murrel & Fried, 2007).They have also been recorded, although less frequently, from pinnipeds, such as harbour seals, subantarctic fur seals and Stellar's sea lions. On the contrary, adult worms in the *Pseudoterranova decipiens* complex have been found mostly in pinnipeds (Murrel & Fried, 2007), however, several authors have reported the presence of Pseudoterranova sp. in bottlenose dolphins (Abollo *et al*., 1998; Gibson *et al*., 1998; Sánchez *et al*., 2002; Colom-Llavina, 2005). Furthermore, Contracaecum sp. has been also found in bottlenose dolphins (Abollo *et al*., 1998; Gibson *et al*., 1998; Sánchez *et al*., 2002; Colom-Llavina, 2005).

Anisakis simplex is found in all three cetacean species because of its worldwide distribution and its preference for cooler temperate waters. Also, the majority of the studies carried out on this topic are from cold temperate waters, so it is not a surprise to find *A. simplex* in all of them. *Pseudoterranova decipiens* is also found in cold temperate waters but its most common final hosts are pinnipeds, although it has been reported in some cetacean species. Furthermore, *Contracaecum sp*. can be found in piscivorous birds as well as cetaceans and pinnipeds. Therefore, more studies need to be conducted regarding parasites in pinnipeds and piscivorous birds as well as cetaceans to improve our knowledge.

Young (1972) observed that although it is known cetaceans are important hosts of *A. simplex*, because of the differences in the collecting techniques, unfortunately it is not possible to apply valid tests of significance to the differences in the numbers of nematodes in cetaceans.

Comparing the results obtained by undergraduate students from University of College Cork, we can observe that the prevalence is different for each specie and season. These results agree with previous reports that stated the abundance of Anisakis may fluctuate quite dramatically with time (Smith & Wootten, 1978). Several reasons could influence the presence of Anisakis, thus regular studies need to be carried out to be able to identify what causes the presence of Anisakis.

Several studies have been carried out regarding Anisakine parasites on several commercially exploited fish species, all important to human consumption. Noguera et al. (2009) studied the prevalence of *Anisakis simplex* in wild Atlantic salmon and found that it varies from 65 to 100% in the North, West and East Atlantic. However, there is not enough work on Anisakis spp. infection in salmon in comparison to that on other commercially exploited fish such as Atlantic cod *Gadus morhua*, herring *Clupea harengus*, haddock *Melanogrammus aeglefinus*, mackerel *Scomber scombrus*, monkfish *Lophius piscatorius* and whiting *Merlangius merlangus*.

Perdiguero (2008) conducted a study in six regions within the North East Atlantic on Anisakine parasites in cod and her results showed that *Anisakis simplex* and *Hysterothylacium aduncum* presented high prevalence and abundance in the overall sample (prevalence 53.4% and 83.9%, respectively; mean abundance 85.27 and 31.58, respectively). Concretely, in the Celtic Sea nematodes represented over 85% of individual parasites, *A. simplex*, *H. aduncum* and *C. osculatum* being the three most representative species which comprised 42%, 24% and 5% of the total nematode abundance. Also, the Irish Sea collection showed a relatively low abundance of nematodes which represented 57% of all parasites and a higher abundance of trematodes. Several authors have suggested that *A. simplex* and *C. osculatum* are able to utilize fish host species that are available at a given location, and this behaviour coupled with the vagility[1] of the final hosts (marine mammals), may explain the wide distribution and abundance of these species.

[1] Vagility: capacity or tendency of an organism or a species to move about or disperse in a given environment.

5. Conclusion and Future research

This study is a collection of all the information available regarding the presence of cetaceans with the presence of digestive parasites of the Fm. Anisakidae. Although several authors agree that cetaceans are definitive hosts of parasites of the Fm. Anisakidae, there is not enough information on levels of parasitism for each species. Also, the differences in the collecting techniques make it impossible to compare and to apply valid tests of significance to the differences in the numbers of nematodes in cetaceans. Moreover, a higher presence of cetaceans in Irish waters could indicate a greater level of parasitism; however, there is not enough information to accept or reject this hypothesis.

Volunteers and ordinary people's involvement in reporting sightings and strandings and their coordination with field experts are vital for obtaining a raw estimate of the cetacean abundance in any waters. There are still many things concerning cetaceans that remain unknown, hence future research should focus on filling those blanks. Also, more knowledge determining the causes why a cetacean strands is needed. Therefore, in order to carry out a post-mortem exam in the majority of the stranded cetaceans a joint effort is needed. Also, there is not enough information on the biology and ecology of most of the marine mammals, so future research should focus in getting a better knowledge of each marine species and the possible factors that may affect their biology and disturb their habitat.

Several reasons could influence the presence of Anisakis, thus regular studies need to be carried out to be able to identify what causes the presence of Anisakis. In order to do that, studies should take into account all trophic levels. Also, these studies should include areas highly humanized such as harbours and fishing areas; where high rates of discards can be found, which could stimulate the presence of Anisakis. Furthermore, studies on diet could help us to understand their complex life cycle. As well, it is important to identify its intermediate and final hosts in each region and study its optimal conditions to grow (e.g. temperature).

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7. Appendix

7.1 Appendix I

Universitat de Girona

GMIT GALWAY-MAYO INSTITUTE OF TECHNOLOGY

My name is Lídia Sarrà Alarcón and I am a Master of Science student at University of Girona (Spain). I have got an Erasmus scholarship with GMIT for the next three months.

The idea of my research is to analyze if there is a relation between the presence/absence of cetacean's population with the increase of parasites in fish populations.

Contact details: u1903397@correu.udg.edu *or* lidia_sarra_alarcon@hotmail.com

Contact at UdG: **Dr. Margarida Casadevall** (margarida.casadevall@udg.edu)

Contact at GMIT: **Dr. Pauline King** (Pauline.King@gmit.ie)

I would appreciate if you can fill up the following questionnaire.

QUESTIONNAIRE

Name: __DR. EMER ROGAN__________________________ **Date:** _19/12/2009______

Institution/Research Group: ZEPS DEPARTMENT – UNIVERSITY COLLEGE CORK (UCC)

1) **Which species are most frequently found during strandings? Write numbers from 1 to 4. (Note: 1 is the most frequent and 4 is the less frequent).**

   a) *Tursiops truncatus* 4
   b) *Delphinus delphis* 2
   c) *Stenella coeruleoalba* 3
   d) *Ziphius cavirostris* 4
   e) Others: _Harbour porpoise (*Phocoena phocoena*) 1

2) **How often do they strand?**

   Stranding frequency varies with species, season and year. See review paper.

3) **Which months of the year have more strandings? Why?**

   Autumn/Winter months – different spatial distribution, increase in fisheries interaction?

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4) **Is there a place where they strand more often? Where?**

All irish coastal waters, but mostly western and southern coastline – more species and higher abundance, arguably better observer cover

5) **How many years of data have you collected?**

   a) 1 to 5 years.
   b) 5 to 10 years.
   c) More than 10 years.

6) **Do you do necropsies on the stranded cetaceans?**

   a) Yes, we do.
   b) No, we don't. (Continue to question 10)
   c) No, but we know someone that does.
   Name and contact details: ____________________________
   (Continue to question 10)

7) **Have you seen any parasite (especially from the *Anisakidae* family) during those necropsies?**

   a) Yes, we have.
   b) No, we haven't (Continue to question 10)
   c) Others: ______________________________
   (Continue to question 9)

8) **Have you analyzed any parasite found during those necropsies? Do you know someone that does?**

Yes we have done analysis

9) **How many parasites have you seen in one cetacean?**

   a) 1 to 10.
   b) 10 to 50.
   c) More than 50.
   d) Others: No parasites varies with species, sex and age – so from 0 – over 1K

10) **Do you know any other researcher that has recollected data from strandings, necropsies or parasite infections in cetacean?**

No – not in Ireland; Toni Raga in Spain other person with interest in parasites.

Sometimes German strandings scheme also look at parasite composition in detail.

7.2 Appendix II

Table 3. Harbour porpoise strandings data.

HARBOUR PORPOISE STRANDINGS	January	February	March	April	May	June	July	August	September	October	November	December	TOTAL	MEAN	STDEV
2009	4	5	3	3	2	6	4	1	2	2	2	2	36	3	1.48
2008	4	4	6	4	5	1	4	3	1	1	2	4	39	3.25	1.66
2007	4	4	3	4	3	3	1	4	2	5	2	7	42	3.5	1.57
2006	4	2	5	2	2	4	3	2	0	0	0	3	27	2.25	1.66
2005	6	4	3	0	3	3	1	1	1	2	4	1	29	2.42	1.73
2004	3	6	7	3	0	7	5	3	1	3	5	2	45	3.75	2.26
2003	10	6	7	1	0	1	4	2	3	3	1	3	41	3.42	2.94
2002	2	5	4	2	0	4	4	3	5	5	3	0	37	3.08	1.78
2001	11	2	6	4	1	1	3	3	2	0	1	5	39	3.25	3.02
2000	0	3	4	2	0	0	1	2	0	0	2	5	19	1.58	1.73
1999	5	2	4	1	0	2	3	0	0	2	0	1	20	1.67	1.67
1998	0	2	2	0	1	0	0	0	1	1	1	0	8	0.67	0.78
1997	4	0	2	1	0	1	0	0	0	0	1	2	11	0.92	1.24
1996	2	2	2	1	0	0	0	0	1	2	0	0	10	0.83	0.94
1995	1	0	0	0	1	0	1	2	0	0	0	1	6	0.5	0.67
1994	0	1	1	0	1	0	0	0	0	0	0	0	3	0.25	0.45
1993	1	4	2	0	1	1	0	0	1	0	0	0	10	0.83	1.19
1992	0	0	2	0	0	0	1	0	1	0	0	1	5	0.42	0.67
1991	1	3	0	0	0	1	1	0	1	2	0	1	10	0.83	0.94
1990	1	0	5	0	0	0	0	0	1	1	1	1	10	0.83	1.40
1989	1	2	1	0	1	0	1	0	0	1	2	0	9	0.75	0.75
TOTAL	64	57	69	28	21	35	37	26	23	30	27	39			
MEAN	3.05	2.71	3.29	1.33	1	1.67	1.76	1.24	1.09	1.43	1.29	1.86			
STDEV	3.07	1.92	2.12	1.49	1.34	2.08	1.70	1.37	1.22	1.57	1.42	1.98			

Table 4. Harbour porpoise sightings data.

HARBOUR PORPOISE SIGHTINGS

	January	February	March	April	May	June	July	August	September	October	November	December	TOTAL	MEAN	STDEV
2009	33	46	16	27	36	56	71	57	74	32	27	13	488	40.67	20.15
2008	42	37	27	45	50	52	78	92	87	32	41	37	620	51.67	21.84
2007	50	37	24	55	29	62	82	93	63	44	26	22	587	48.92	23.12
2006	37	21	20	35	28	70	92	54	45	37	17	31	487	40.58	22.11
2005	35	19	29	29	37	49	98	96	44	38	36	22	532	44.33	25.99
2004	10	15	24	22	43	23	102	51	45	27	32	22	416	34.67	24.51
2003	14	7	8	13	13	34	41	72	74	30	12	20	338	28.17	23.49
2002	7	3	8	9	6	8	40	36	17	20	19	28	201	16.75	12.31
2001	20	10	15	14	27	30	68	64	56	22	12	16	354	29.5	20.99
2000	14	11	11	8	4	14	4	5	13	16	3	5	108	9	4.69
1999	1	0	2	3	1	5	10	7	1	16	11	10	67	5.58	5.16
1998	1	0	2	0	2	9	4	7	4	0	1	0	30	2.5	2.97
1997	0	0	2	1	6	1	1	7	5	1	0	0	24	2	2.52
1996	4	2	3	9	12	57	44	34	6	5	2	2	180	15	18.98
1995	1	1	2	1	9	29	25	87	19	4	3	9	190	15.83	24.46
1994	1	1	4	4	3	36	21	18	4	10	4	2	108	9	10.74
1993	1	0	4	1	2	16	16	29	14	20	3	4	110	9.17	9.47
1992	1	0	2	1	1	6	7	3	6	6	0	0	33	2.75	2.73
1991	0	0	0	0	1	2	2	9	3	1	0	1	19	1.58	2.54
1990	0	0	0	2	0	0	2	2	1	0	0	0	7	0.58	0.90
1989	0	0	1	0	0	0	1	0	0	1	0	0	3	0.25	0.45
TOTAL	272	210	204	279	310	559	809	823	581	362	249	244			
MEAN	12.95	10	9.71	13.28	14.76	26.62	38.52	39.19	27.67	17.24	11.86	11.62			
STDEV	16.41	14.26	9.83	16.19	16.27	23.17	36.40	34.33	28.89	14.42	13.34	11.80			

Table 5. Short-beaked common dolphin strandings data.

SHORT-BEAKED COMMON DOLPHIN STRANDINGS

	January	February	March	April	May	June	July	August	September	October	November	December	TOTALS	MEAN	STDEV
2009	2	2	1	3	2	0	3	5	1	1	1	2	23	1.92	1.31
2008	2	2	2	2	1	1	3	5	0	2	3	2	25	2.08	1.24
2007	7	5	7	3	4	0	0	3	5	3	2	5	44	3.67	2.31
2006	5	4	3	2	3	6	2	3	3	2	3	4	40	3.33	1.23
2005	6	4	3	1	0	3	0	1	1	1	2	2	24	2	1.76
2004	2	5	6	3	1	0	0	4	4	1	1	1	28	2.33	2.01
2003	2	5	8	6	2	2	1	1	1	1	1	1	31	2.58	2.39
2002	0	2	3	1	4	2	1	0	0	0	2	0	15	1.25	1.35
2001	0	5	3	0	1	0	2	1	0	2	0	0	14	1.17	1.59
2000	1	1	1	0	0	0	0	0	0	0	2	2	7	0.58	0.79
1999	2	4	0	2	0	1	1	1	0	0	0	1	12	1	1.20
1998	0	2	1	2	0	0	1	3	3	1	0	0	13	1.08	1.16
1997	2	1	1	1	0	1	0	0	0	0	1	0	7	0.58	0.67
1996	0	0	1	0	0	2	0	1	0	0	1	0	5	0.42	0.67
1995	0	0	0	0	0	0	1	0	0	0	0	1	2	0.17	0.39
1994	2	3	0	0	0	0	0	0	0	2	0	0	7	0.58	1.08
1993	0	1	0	1	0	0	1	0	0	0	0	0	3	0.25	0.45
1992	1	6	3	1	0	0	0	1	1	2	0	0	15	1.25	1.76
1991	1	1	0	0	1	2	0	0	0	3	1	0	9	0.75	0.96
1990	0	0	3	0	0	0	0	1	0	0	3	0	7	0.58	1.16
1989	1	0	1	0	0	1	0	0	0	0	0	0	3	0.25	0.45
TOTALS	36	53	47	28	19	21	16	30	19	21	23	21			
MEAN	1.71	2.52	2.24	1.33	0.90	1	0.76	1.43	0.90	1	1.09	1			
STDEV	2.00	1.99	2.32	1.53	1.34	1.48	0.99	1.69	1.51	1.05	1.09	1.41			

Table 6. Short-beaked common dolphin sightings data.

SHORT-BEAKED COMMON DOLPHIN SIGHTINGS

	January	February	March	April	May	June	July	August	September	October	November	December	TOTAL	MEAN	STDEV
2009	4	7	6	4	7	13	17	24	27	33	8	8	158	13.17	9.84
2008	11	7	3	7	21	6	19	42	34	29	23	12	214	17.83	12.37
2007	13	6	14	9	6	10	21	88	47	25	20	10	269	22.42	23.56
2006	8	10	0	6	6	6	11	44	26	29	16	7	169	14.08	12.69
2005	11	8	6	4	4	11	33	96	41	18	18	19	269	22.42	25.83
2004	12	11	14	5	32	8	36	38	18	10	5	6	195	16.25	12.17
2003	12	8	9	7	8	18	13	44	33	33	7	8	200	16.67	12.75
2002	4	10	7	2	0	3	9	22	16	9	14	9	105	8.75	6.31
2001	8	14	3	1	2	14	22	49	24	10	23	16	186	15.5	13.25
2000	9	1	2	0	0	2	0	2	14	0	1	0	31	2.58	4.38
1999	0	5	5	0	0	0	5	5	6	2	5	1	34	2.83	2.52
1998	2	0	1	0	1	5	16	1	2	1	0	2	31	2.58	4.44
1997	3	1	0	0	13	2	6	12	11	0	1	0	49	4.08	5.09
1996	3	0	0	8	1	20	19	21	6	12	4	7	101	8.42	7.81
1995	0	4	0	6	4	10	7	18	21	5	21	14	110	9.17	7.60
1994	5	0	0	0	3	4	8	9	6	4	1	0	40	3.33	3.23
1993	0	0	1	0	1	11	3	11	4	21	6	1	59	4.92	6.45
1992	0	0	0	0	1	0	0	6	0	4	0	1	12	1	1.95
1991	0	1	0	0	0	0	1	1	0	0	0	0	3	0.25	0.45
1990	0	0	0	0	0	0	0	0	2	0	0	0	2	0.17	0.58
1989	0	0	0	0	0	0	0	0	1	4	0	0	5	0.42	1.16
TOTAL	105	93	71	59	110	143	246	533	339	249	173	121			
MEAN	5	4.43	3.38	2.81	5.24	6.81	11.71	25.38	16.14	11.86	8.24	5.76			
STDEV	4.81	4.53	4.49	3.25	8.04	6.13	10.60	27.52	14.34	11.83	8.57	5.96			

Table 7. Bottlenose dolphin strandings data.

	BOTTLENOSE DOLPHIN STRANDINGS														
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**TOTAL**	**MEAN**	**STDEV**
2009	0	0	1	1	0	1	5	2	1	0	0	1	12	1	1.41
2008	0	0	0	0	0	1	1	0	0	1	0	2	5	0.42	0.67
2007	2	0	2	0	0	0	0	0	1	0	0	3	8	0.67	1.07
2006	0	0	0	1	0	0	1	1	2	0	1	0	6	0.5	0.67
2005	1	1	0	1	1	0	1	1	1	0	0	1	8	0.67	0.49
2004	0	0	0	1	0	2	0	0	1	2	3	1	10	0.83	1.03
2003	0	0	0	0	0	0	0	0	0	0	1	1	2	0.17	0.39
2002	0	0	0	0	0	0	1	0	0	0	1	0	2	0,17	0.39
2001	1	0	0	0	0	0	2	1	2	1	0	0	7	0.58	0.79
2000	0	0	1	0	0	0	0	0	0	0	1	0	2	0.17	0.39
1999	0	0	1	0	0	0	1	2	0	0	0	0	4	0.33	0.65
1998	0	0	1	0	0	0	0	0	0	0	0	0	1	0.08	0.29
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	1	0	1	0	0	0	0	2	0.17	0.39
1992	0	0	1	0	0	0	0	0	1	0	1	0	3	0.25	0.45
1991	0	0	0	1	0	1	1	1	0	0	0	0	4	0.33	0.49
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	1	2	0	1	1	0	0	0	0	0	5	0.42	0.67
TOTAL	4	1	8	7	1	7	14	9	9	4	8	9			
MEAN	0.19	0.05	0.38	0.33	0.05	0.33	0.67	0.43	0.43	0.19	0.38	0.43			
STDEV	0.51	0.22	0.59	0.58	0.22	0.58	1.15	0.68	0.68	0.51	0.74	0.81			

Table 8. Bottlenose dolphin sightings data.

	BOTTLENOSE DOLPHIN SIGHTINGS														
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**TOTALS**	**MEAN**	**STD**
2009	2	6	8	23	31	45	26	29	23	18	3	8	222	18.5	13.33
2008	2	4	4	21	51	31	27	42	34	8	3	12	239	19.92	16.91
2007	3	11	3	13	15	37	45	34	32	9	4	8	214	17.83	14.93
2006	5	10	17	20	23	34	35	15	15	14	5	6	199	16.58	10.14
2005	9	4	6	11	11	16	49	27	12	3	9	8	165	13.75	12.76
2004	1	2	4	4	30	34	13	37	12	12	3	2	154	12.83	13.33
2003	21	8	6	3	1	17	16	29	21	8	2	3	135	11.25	9.22
2002	3	1	2	11	7	9	14	16	11	5	5	18	102	8.5	5.60
2001	2	0	3	3	25	25	28	18	15	10	3	0	132	11	10.71
2000	1	0	0	0	1	3	0	1	2	1	2	0	11	0.92	0.99
1999	0	2	7	1	2	10	3	3	4	2	1	0	35	2.92	2.94
1998	1	0	1	0	1	1	1	2	3	2	0	4	16	1.33	1.23
1997	0	1	0	1	4	7	3	6	0	3	0	0	25	2.08	2.50
1996	0	0	1	1	10	3	9	6	7	1	1	0	39	3.25	3.72
1995	1	0	0	1	7	21	27	23	2	0	8	0	90	7.5	10.19
1994	0	0	0	0	8	8	5	10	0	1	0	0	32	2.67	3.91
1993	0	0	0	3	3	15	2	5	11	1	0	0	40	3.33	4.87
1992	0	1	0	0	2	0	3	4	1	1	1	0	13	1.08	1.31
1991	0	0	0	0	1	1	0	0	0	0	0	0	2	0.17	0.39
1990	0	0	1	0	0	0	0	0	0	0	0	0	1	0.08	0.29
1989	0	0	0	0	0	0	0	0	0	1	0	0	1	0.08	0.29
TOTALS	51	50	63	116	233	317	306	307	205	100	50	69			
MEAN	2.43	2.38	3	5.52	11.09	15.09	14.57	14.62	9.76	4.76	2.38	3.29			
STD	4.78	3.50	4.13	7.70	13.56	14.20	15.60	13.73	10.52	5.26	2.63	4.99			

Table 9. IWDG data on Irish strandings (left) and sightings (right) over the past 20 years breakdown by species (based on best estimates).

Bar chart data			
Species	Strandings	Best est	Avg/ stranding
"cetacean" species	31 1.9%	33 1.8%	1.1
"dolphin" species	16 1%	16 0.9%	1
"dolphin" species, possibly harbour porpoise	98 6.1%	100 5.5%	1
"whale" species	31 1.9%	31 1.7%	1
atlantic white-sided dolphin	117 7.3%	140 7.8%	1.2
basking shark	14 0.9%	14 0.8%	1
beaked whale sp	8 0.5%	8 0.4%	1
bottlenose dolphin	82 5.1%	100 5.5%	1.2
common dolphin	308 19.3%	379 21%	1.2
common or striped dolphin	23 1.4%	23 1.3%	1
Cuvier's beaked whale	20 1.3%	20 1.1%	1
fin whale	18 1.1%	18 1%	1
Gervais' beaked whale	1 0.1%	1 0.1%	1
harbour porpoise	358 22.5%	365 20.3%	1
humpback whale	3 0.2%	3 0.2%	1
killer whale	3 0.2%	3 0.2%	1
lagenorhynchus species	1 0.1%	1 0.1%	1
large whale species	1 0.1%	1 0.1%	1
leatherback turtle	4 0.3%	4 0.2%	1
loggerhead turtle	4 0.3%	4 0.2%	1
minke whale	60 3.8%	60 3.3%	1
northern bottlenose whale	11 0.7%	15 0.8%	1.4
pilot whale	143 9%	195 10.8%	1.4
pygmy sperm whale	6 0.4%	6 0.3%	1
Risso's dolphin	44 2.8%	46 2.6%	1
sei whale	1 0.1%	1 0.1%	1
Sowerby's beaked whale	9 0.6%	9 0.5%	1
sperm whale	39 2.4%	39 2.2%	1
striped dolphin	118 7.4%	145 8%	1.2
True's beaked whale	2 0.1%	2 0.1%	1
white-beaked dolphin	20 1.3%	20 1.1%	1
Totals	1594 100%	1802 100%	1.1

Bar chart data			
Species	Sightings	Best est	Avg/ sighting
	20 0.1%	%	
"cetacean" species	65 0.5%	174 0.1%	2.7
"dolphin" species	360 2.6%	5280 3.5%	14.7
"dolphin" species, possibly harbour porpoise	561 4%	4527 3%	8.1
"whale" species	131 0.9%	216 0.1%	1.6
atlantic white-sided dolphin	70 0.5%	920 0.6%	13.1
basking shark	680 4.8%	2152 1.4%	3.2
beaked whale sp	3 0%	6 0%	2
blue whale	1 0%	1 0%	1
bottlenose dolphin	1874 13.3%	20610 13.5%	11
common dolphin	2213 15.8%	86534 56.7%	39.1
common or striped dolphin	32 0.2%	632 0.4%	19.8
distinct dorsal	7 0%	9 0%	1.3
false killer whale	1 0%	2 0%	2
fin whale	634 4.5%	2466 1.6%	3.9
harbour porpoise	4351 31%	18504 12.1%	4.3
humpback whale	151 1.1%	241 0.2%	1.6
indistinct dorsal	2 0%	6 0%	3
killer whale	142 1%	417 0.3%	2.9
lagenorhynchus species	6 0%	28 0%	4.7
large fin	17 0.1%	56 0%	3.3
large whale species	189 1.3%	310 0.2%	1.6
leatherback turtle	35 0.2%	55 0%	1.6
medium whale sp	40 0.3%	174 0.1%	4.4
minke whale	1660 11.8%	2841 1.9%	1.7
minke/northern bottlenose whale	4 0%	6 0%	1.5
northern bottlenose whale	12 0.1%	24 0%	2
patterned dolphin species	58 0.4%	1266 0.8%	21.8
pilot whale	131 0.9%	1648 1.1%	12.6
Risso's dolphin	449 3.2%	2821 1.8%	6.3
seal species	2 0%	2 0%	1
sei whale	4 0%	4 0%	1
sei, fin or blue whale	100 0.7%	257 0.2%	2.6
sperm whale	14 0.1%	25 0%	1.8
striped dolphin	11 0.1%	118 0.1%	10.7
turtle species	4 0%	4 0%	1
walrus	2 0%	2 0%	1
white-beaked dolphin	24 0.2%	238 0.2%	9.9
Totals	14040 100%	152576 100%	10.9

7.3 Appendix III

Table 10. Prevalence results from undergraduate projects from University College Cork (UCC). Data obtained from Dr. Emer Rogan.

Anisakis spp	- host species Harbour porpoise (n = 12) 100% prevalence (BSc undergraduate project Hickey 2006)
	- host species harbour porpoise (n = 26) 46% prevalence (BSc project O'Leary, 1996)
	- host species Common dolphin (n = 25) 68% prevalence (MSc thesis Nahadajah 1995)

PART II: "A comparison of common dolphin, *Delphinus delphis*, Linnaeus (1758) whistles at two locations in Irish waters"

Abstract

Sound in cetaceans is broadly used for communication, navigation, prey detection and capture, making it an essential tool. The signal for communication mostly used for odontocetes is a narrowband tonal whistle, described based on spectrogram views of their time-frequency contours. The aim of this study is to describe and compare the whistle characteristics of two populations of short-beaked common dolphins, *Delphinus delphis*, around Ireland. The results showed that there was no significant difference for all the variables, except for the number of harmonics, for which the test showed a significant difference between the two locations ($t=-4.14$; $df= 360$; $p<0.05$), which lead us to conclude that either they were the same population that moves in search for food or two different populations so close geographically and/or genetically that no variations can be detected. Also, the results showed that the most common whistle type for both locations was Downsweep. The first sub-type accounted for most of whistles in both locations, which may suggest that the whistles recorded in this study consisted of non-signature whistles. Furthermore, this study proves that acoustic monitoring alone does not provide enough information in relation to short-beaked common dolphin populations around Ireland and therefore a combined approach with visual data may be considered for further research.

Keywords: odontocetes, whistles, *Delphinus delphis*, Ireland, spectrogram, acoustic surveys.

1. Introduction

1.1 Sound production in cetaceans

Sound travels in water about five times faster than in air. Sound velocity in air is approximately 340m/s and in water between 1450 and 1550m/s depending on temperature and salinity (which vary with depth), (Berta *et al.*, 2006). The basic mechanisms for sound production in cetaceans are similar to that in terrestrial mammals; the sound is made by passing air under pressure through the membranes, which vibrate (Mann, 2000).

Cetaceans rely on sound as their main sense of communication, navigation, prey detection and capture (Richardson *et al*., 1995; Aguilar de Soto *et al*., 2004). They are capable of visualizing their environment through echolocation (Richardson *et al*., 1995; Reynolds & Rommel, 1999). The emitted sounds are reflected on the nearby objects, which give them information about what is in front of them (Carwardine, 1998). Some vocalize more frequently than others, making them better subjects for acoustic surveys (Richardson *et al*., 1995; Mellinger *et al*., 2007). Vocalizing behaviour varies with species (**Fig. 1**), gender, age, and season, for example, adult males of many baleen whale species vocalize regularly and loudly during the breeding season, (Mellinger *et al*., 2007), and even within species (Ansmann *et al*., 2007).Their vocalization frequencies extend the range of humans (Berta *et al.*, 2006).

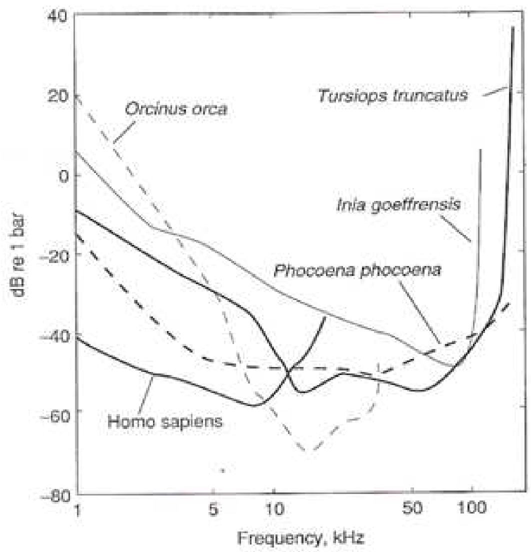

Figure 1. Audiograms for several species of odontocetes (Berta *et al*., 2006).

Dolphins produce a large variety of whistle-like sounds (Richardson *et al*., 1995; Aguilar de Soto *et al*., 2004; Ansmann *et al.*, 2007). Their phonations can be grouped into three categories:

- **Whistles**: are narrowband tonal calls, frequency modulated signals used for communication (Aguilar de Soto *et al*., 2004; Hildebrand, 2007; Rankin *et al*., 2008). Their frequencies oscillate between 2 and 30 kHz (Hildebrand, 2007; Rankin *et al*., 2008). Their duration is up to a few seconds (Ansmann *et al*., 2007).

- **Burst pulse calls**: are rapid series of broadband clicks (Aguilar de Soto *et al.*, 2004; Hildebrand, 2007) and have very short inter-pulse intervals (Rankin *et al.*, 2008). They range from 5-150 kHz and are thought to be used for communication (Hildebrand, 2007; Rankin *et al.*, 2008), and may also be utilized for echolocation (Rankin *et al.*, 2008).

- **Echolocation clicks**: are short, broadband, pulsed sounds used for navigation and object detection (Richardson *et al.*, 1995; Reynolds & Rommel, 1999; Mann, 2000; Hildebrand, 2007; Rankin *et al.*, 2008). They have peaked frequencies ranging from tens of kilohertz to well over 100 kHz (Rankin *et al.*, 2008).

This research shall concentrate on the whistle phonations due to the feasibility of analysis. Burst-pulse calls and echolocation have frequencies too high for the instrumentation to pick up a signal; therefore it is not feasible to work with them (Richardson *et al.*, 1995). Whistles are frequency modulated and commonly described based on spectrogram views of their time-frequency contours (**Fig. 2**), (Richardson *et al.*, 1995). Furthermore, Richardson *et al.* (1995) described 6 different contour categories: constant frequency (Type A), upsweeps (Type B), downsweeps (Type C), U-shapes (or convex), (Type D), U-shapes (or concave), (Type E) and sinusoidal (Type F) whistles (see **Material and Methods**). Nevertheless, not all the whistles follow this rule, they are often more complex and they may even be a combination of different types (Ansmann *et al.*, 2007). In another study conducted in the Celtic and Irish Sea, Wakefield (2001) found 18 different types of whistles with varying degrees of frequency modulation, which include the six types generally used (constant, upsweep, downsweep, convex, concave and sinusoidal).

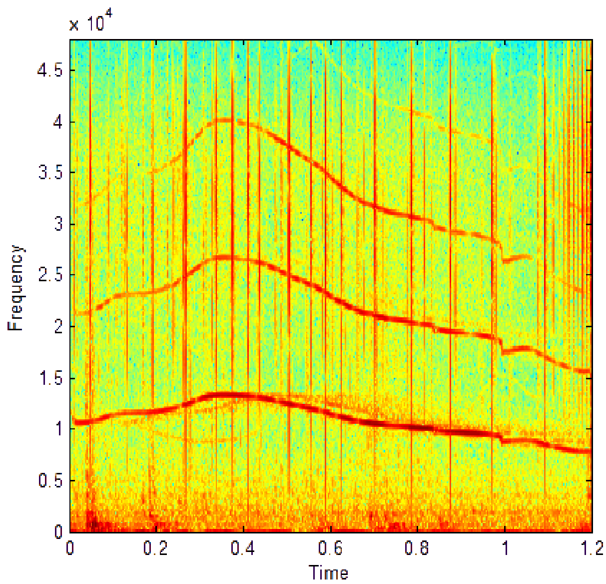

Figure 2. Spectogram of a short-beaked common dolphin whistle call with three harmonics.

Concept of the "signature whistles" hypothesis

The hypothesis of "signature whistles" was first introduced by Caldwell and Caldwell in 1965, while they were studying the acoustic characteristics of captive Bottlenose dolphins (*Tursiops truncatus*).They observed that each dolphin within a group produces a distinctive whistle contour, allowing the identification of individual animals (Richardson *et al*., 1995; Berta *et al*., 2006; Ansmann *et al*., 2007). Moreover, they hypothesized that the "signature whistle" served not only as a form of individual identification (Mann, 2000) but also as a communication tool to convey valuable information to the dolphin group, such as their state of arousal or fear (Berta *et al*., 2006). Their results showed that over 90% of the individual's vocalizations used the same contour with light differences in duration and/or intensity (Richardson *et al*., 1995; McCowan & Reiss, 2001; Ansmann *et al*., 2007). Bottlenose dolphins appear to develop a highly stable signature whistle (**Fig. 3**) within the first year or so of life (Mann, 2000). The signature whistle hypothesis has become widely accepted and has focused on bottlenose dolphins, with few studies on Atlantic spotted dolphins, common dolphins and Pacific white-sided dolphins (Scullion, 2004).

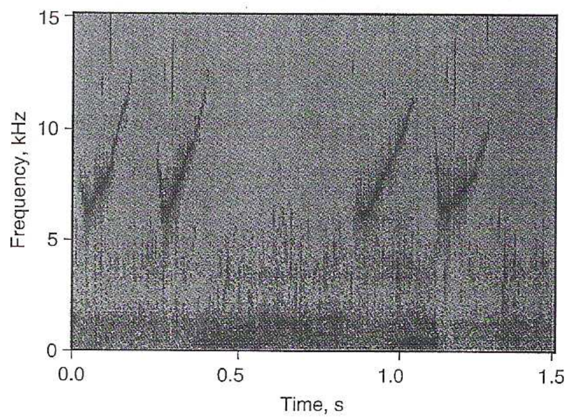

Figure 3. Spectrogram of a repeated spotted dolphin signature whistle (Berta *et al*., 2006).

In 1990, Caldwell *et al*. reported that bottlenose dolphins produce a highly variable collection of whistles that are not individually distinctive, called the "variant whistles" (Richardson *et al*., 1995). These whistles can be very diverse, there can also be considerable overlap in the repertoires of variant whistles form different individuals (Mann, 2000). Dolphins generally produce signature whistles whilst in isolation, which supports the hypothesis that dolphins use signature whistles to maintain contact with individuals from whom they have been separated (Mann, 2000). It is also useful for maintaining contact with individuals which may not be within close visible range during foraging (Ansmann *et al*., 2007).

McCowan & Reiss (2001) conducted a study replicating the approach and methodologies used in the studies that originally and subsequently characterized signature whistles. Their results showed that 10 out of 12 dolphins used a predominant and shared whistle type rather than an individually distinctive signature whistle. The function of this call within species or social groups is thought to be related to maintain individual recognition between parents and offspring, between mates and even between neighbours. They concluded that there is no evidence for individually distinctive signature whistle contours on the dolphins studied. Other studies on wild bottlenose dolphin populations suggest that even though there may be differences between whistles from different individuals within the same population, there are still some characteristics that are unique for each population (Berta *et al*., 2006). In another study, the fact that common dolphin whistle repertoires were neither individually-specific nor context-specific led Moore and Ridgway (1995) to suggest that they may represent a form of regional dialects, similar to the pod-specific dialects proposed for killer whales (Berta *et al.*, 2006; Ansmann *et al*., 2007).

Ansmann *et al*. (2007) conducted a study on short-beaked common dolphins from the Celtic Sea and English Channel. Her results showed that from 1835 whistles recorded in the Celtic Sea and 435 recorded from the English Channel, the simplest whistle type was the most common whistle recorded. The simplest whistle type was also the most common whistle recorded by Wakefield (2001) and Scullion (2004). That led her to conclude that a large part of the repertoire of common dolphins in the Celtic Sea consists of non-signature whistles.

1.2 Acoustic surveys vs. Visual surveys

Visual surveys

Visual surveys are a method of identifying of cetaceans using the human eye or 25X binoculars. It can be carried out from shore or from a boat. Identification of individuals may be assisted by the use of archived photos illustrating particular characteristics such as dorsal fin notches. Therefore, this method requires that the individuals show any distinctive marks (Mellinger *et al*., 2007). Moreover, some individuals may be missed by the visual observer (Oswald *et al.*, 2003; Rankin *et al*., 2008). Also, another limitation to this method is that it relies on daylight hours, weather conditions (Mellinger *et al*., 2007, Oswald *et al.*, 2003, Rankin *et al*., 2008) and animal behaviour (Oswald *et al.*, 2003).

Acoustic surveys

Acoustic surveys can augment visual surveys by providing methods for detection and identification of cetaceans when they are likely to be missed by visual observers (Oswald *et al.*, 2003; Van Prijs & Southall, 2007). This may be a particular use for whale species that dive for long periods of time and do not surface within the visual range of observers searching from a moving survey vessel with 25X binoculars (Barlow *et al.*, 1995). It is verified that acoustic detection rates are higher than visual detection rates for odontocetes (see **Section 1.3.1**), especially for porpoises and sperm whales (Barlow *et al.*, 1995; Lewis *et al.*, 1998, Van Prijs & Southall, 2007). Moreover, it is a non-invasive method (Aguilar de Soto et al., 2004).

Acoustic surveys are used to provide information on physical and biological features of ocean areas and also provides enhanced and unique scientific data on (a) living marine resources; (b) biotic and abiotic characteristics of marine ecosystems; and (c) the effects of anthropogenic sound on protected species and their ecosystems (Van Prijs & Southall, 2007) Furthermore, it can be complimentary to visual approaches for the study of marine mammal populations (Mellinger *et al*., 2007; Van Prijs & Southall, 2007). A comparison of both techniques are compared, they often reveal different aspects (i.e. behavioural, spatial or temporal) of the population under study (Van Prijs & Southall, 2007). The use of computerized collection and analysis of acoustic survey data results in a lower labour demand compared to visual surveys (Barlow *et al.*, 1995; Lewis *et al.*, 1998). In recent years, acoustic surveys have been used to study cetacean behaviour and distribution (Lewis *et al.*, 1998).

Acoustic survey data is limited by a few factors. One limitation is that the animals must produce sounds within the frequency range of the equipment (Evans & Hammond, 2004; Rankin *et al*., 2008). Also, the vocalizations of some dolphins can be difficult to distinguish from one another (Evans & Hammond, 2004). Moreover, the cost of equipment, its deployment and its maintenance requirements are high (Evans & Hammond, 2004). Another important limitation is that the system requires substantial calibration of the data (Van Prijs & Southall, 2007).

There are two types of acoustic sampling:

1) <u>Active acoustics</u>: where the sound is transmitted and the returning echo is analyzed (Berta *et al*., 2006). Broadly used for observation of zooplankton and micronekton as well as fisheries research (Mellinger *et al*., 2007).

2) <u>Passive acoustics</u>: where the instrument used does not produce any sounds itself, but captures sounds from the surrounding environment (Mellinger *et al*., 2007). They have proven very reliable for some species (e.g., sperm whales), (Van Prijs & Southall, 2007). Despite their high reliability, they should not be assumed to be a replacement for visual surveys (Van Prijs & Southall, 2007).

   Two different types of sensors can be used:

   - <u>Fixed acoustic sensors</u>: use cabled hydrophones, typically deployed in permanent or semi-permanent installations. They are autonomous recorders (battery powered) typically deployed in arrays of three to ten instruments to provide area coverage. They are good for estimating density of animals around a fixed listening station (Van Prijs & Southall, 2007). This method can be performed year round at relatively low cost (Evans & Hammond, 2004; Mellinger *et al*., 2007; Van Prijs & Southall, 2007) and can be carried out in remote areas that are difficult to survey (e.g. polar regions). Also, fixed acoustic sensor provide data continuously in near real time, that allows rapid response to unusual events (Mellinger *et al*., 2007). The collected data are easier to standardize (Evans & Hammond, 2004). Nevertheless, it is limited by the area of coverage, generally to marine areas immediately adjacent to land, although they can be placed in fixed stations such as oil and gas platforms to expand their area of coverage (Evans & Hammond, 2004). Data is not easily accessible due to their military or sensitive nature and it must be recovered before the analysis can begin (Mellinger *et al*., 2007). The fact that fixed acoustic sensors use stations randomly placed makes it difficult to extrapolate the information to other stations (Van Prijs & Southall, 2007).

- Mobile acoustic sensors: use platforms (such as ferries, oceanographic or fisheries research vessels, oil exploration guard vessels, whalewatching boats, etc.), (Evans & Hammond, 2004), and even marine mammals themselves (attaching tags with a sensor and electronic package). However, this can only be used on larger marine mammals (Mellinger *et al*., 2007). This method has a large area of coverage and simplicity in combining acoustic detection with visual survey (Mellinger *et al*., 2007). Also, mobile acoustic sensors are less likely to be affected by weather conditions (Evans & Hammond, 2004, Mellinger *et al*., 2007; Van Prijs & Southall, 2007) and are more efficient at detecting cetaceans (Evans & Hammond, 2004). Nonetheless, it is not possible to identify the species (Oswald *et al.*, 2003), it has no control over survey and it needs more research on abundance estimates (Evans & Hammond, 2004).

Recent advances in acoustic technology have included the development of t and c-pods. However, the technology is limited as it only detects whether a cetacean is present or not.

1.3. Short-beaked common dolphin, Delphinus delphis, Linnaeus (1758)

1.3.1. General biology and current status

The short-beaked common dolphin, *Delphinus delphis*, belongs to the suborder Odontoceti, which is mainly characterized by the presence of teeth (Carwardine, 1998) and the genus Delphinus, which was named by Linnaeus in 1758 (Dailey & Browell, 1972; Carwardine, 1998). Delphinids are the most diverse of the cetacean families and include 17 genera and 36 extant species of dolphins, killer whales, and pilot whales (Carwardine, 1998; Berta *et al.*, 2006).

The short-beaked common dolphin (**Fig. 4**) is a small cetacean species, reaching lengths of <2.15m (Dailey& Browell, 1972; Carwardine, 1998; Scullion, 2004; Bush, 2006) and weighing up to 200 Kg (Scullion, 2004). Males are generally 10 to 20cm larger than females (Dailey & Browell, 1972; Carwardine, 1998). Females become sexually mature between 5-12 years of age, with males maturing slightly earlier (between 3-12 years of age), (Dailey & Browell, 1972). Neumann & Orams (2005) suggested that they reach sexual maturity around six years of age. Individuals are assumed to live 25 to 30 years (Dailey & Browell, 1972). The body colour of short-beaked common dolphins is distinctive. The dorsal surface is black, the ventral is white, and the sides are ochre and gray (Dailey & Browell, 1972; Carwardine, 1998; Scullion, 2004).

Figure 4. Short-beaked common dolphin (www.nmfs.noaa.gov)

Common dolphins are generally considered to be pelagic, with most groups occurring over the continental shelf and beyond (Neumann & Orams, 2005). They are opportunistic feeders, thus their diet can vary according to geographical locations and seasonal fluctuations in prey distribution and abundance (Bearzi *et al*., 2003; Neumann & Orams, 2005; Bush, 2006). Mainly they feed on pelagic fish such as anchovy, mackerel, herring, sardine and sprat (Santos *et al*., 2004; Scullion, 2004; Neumann & Orams, 2005), although they can also feed on squid (Bearzi *et al*., 2003; Scullion, 2004; Bush, 2006).

According to the IUCN Red List of Threatened Species, this specie is classified as "of least concern" (Hammond *et al*., 2008). However, in 2003 the Mediterranean subpopulation was listed as endangered based on criterion A2, which refers to a 50% reduction in abundance over the last 30 years, the cause of which "may not have ceased or may not be understood or may not be reversible" (Bearzi *et al*., 2003). Over the last 50 years common dolphins have been replaced by striped dolphins in the Mediterranean (Viale, 1994).

1.3.2. Distribution

Common dolphins (*Delphinus spp*., family *Delphinidae*) are considered to be of high abundance with a worldwide distribution (Oswald *et al*., 2003; Santos *et al*., 2004; Neumann & Orams, 2005). They occur frequently in the Atlantic Ocean and its adjacent seas (**Fig. 5**). They are also found in the Indian Ocean and in both the South and North Pacific but they do not migrate into the cold waters (Dailey & Browell, 1972). In general, they occur where the sea surface temperature (SST) oscillates between 10- 28ºC, therefore limiting their distribution to the north and south (Carwardine, 1998).

Figure 5. Common dolphin World distribution map (modified from www.wikipedia.org)

Common dolphins generally remain localized though some populations have been recorded migrating seasonally (Carwardine, 1998). They form large groups, sometimes numbering in the thousands (Neumann & Orams, 2005; Scullion, 2004). Bearzi *et al*. (2003) recorded groups of 50-70 animals in the Mediterranean, with aggregations of 100-600 animals occasionally.

In Ireland, common dolphins can be regularly found in the southern Irish sea and the Celtic Deep area, in the western approaches to the English Channel, around the Inner Hebrides and west of Ireland (**Fig. 6**), (Ansmann, 2005).

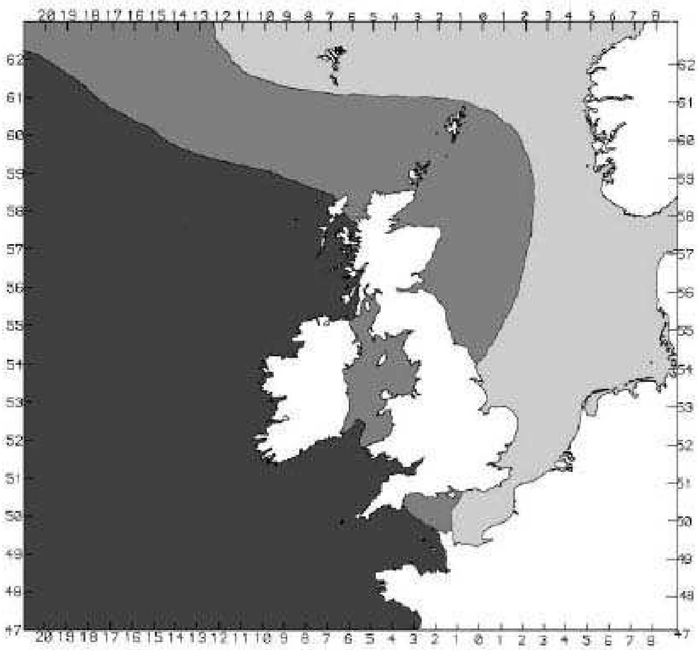

Figure 6. Short-beaked common dolphin distribution around the British Isles. Dark grey: regular occurrence; medium grey: occasional occurrence; light grey: absent/casual (Ansmann, 2005).

1.3.3. Vocal behaviour

Common dolphins are highly vocal animals (Carwardine, 1998; Mellinger *et al*., 2007). Like most delphinids they produce echolocation click trains, burst pulse sounds and whistles (Berta et al., 2006; Ansmann *et al*., 2007). It is estimated that *D.delphis* whistles can be acoustically detected from about 500 metres away (Scullion, 2004). It is thought that social cetaceans, such as short-beaked common dolphin, used the frequency modulated whistles as a mechanism for continuously interacting and maintaining group cohesion, as well as, to coordinate during hunting (Bush, 2006).

Oswald *et al*. (2003) found that short-beaked common dolphin whistles had a mean beginning frequency of 9.8kHz, mean end frequency of 11.4kHz, mean minimum and maximum frequencies of 7.4 and 13.6kHz respectively, a mean frequency range of 6.3kHz, and a mean duration of 0.8s. Their average number of inflection points (see **Material and Methods**) was 1.2 and they had on average 1 step (see **Material and Methods**) within their contours.

Several studies from the short-beaked common dolphins found in the Celtic Sea concluded that their whistles range in frequency from 3.37 to 23.51kHz (Scullion, 2004; Ansmann, 2005; Bush, 2006). Wakefield (2001) results showed that the whistle frequency from the Celtic and Irish Sea ranged from 4.7 to 20.3kHz.

1.4 Objectives

The aim of this study is to describe and compare the whistle characteristics of two populations of short-beaked common dolphins, *Delphinus delphis*, around Ireland.

To achieve our aim two approaches are used:

- Quantitative method: it consists on measuring a range of parameters of each whistle, such as duration, start frequency, end frequency, minimum frequency, maximum frequency, number of inflection points, number of harmonics and steps.
- Classification method: which consists on classify each whistle into several types based on the shape of their frequency versus time contour.

2. Material and Methods

2.1 Data Collection

The audio files were recorded from two sites around Ireland; off Galley Head in Cork and off Blasket Islands in Kerry (**Fig. 7**).

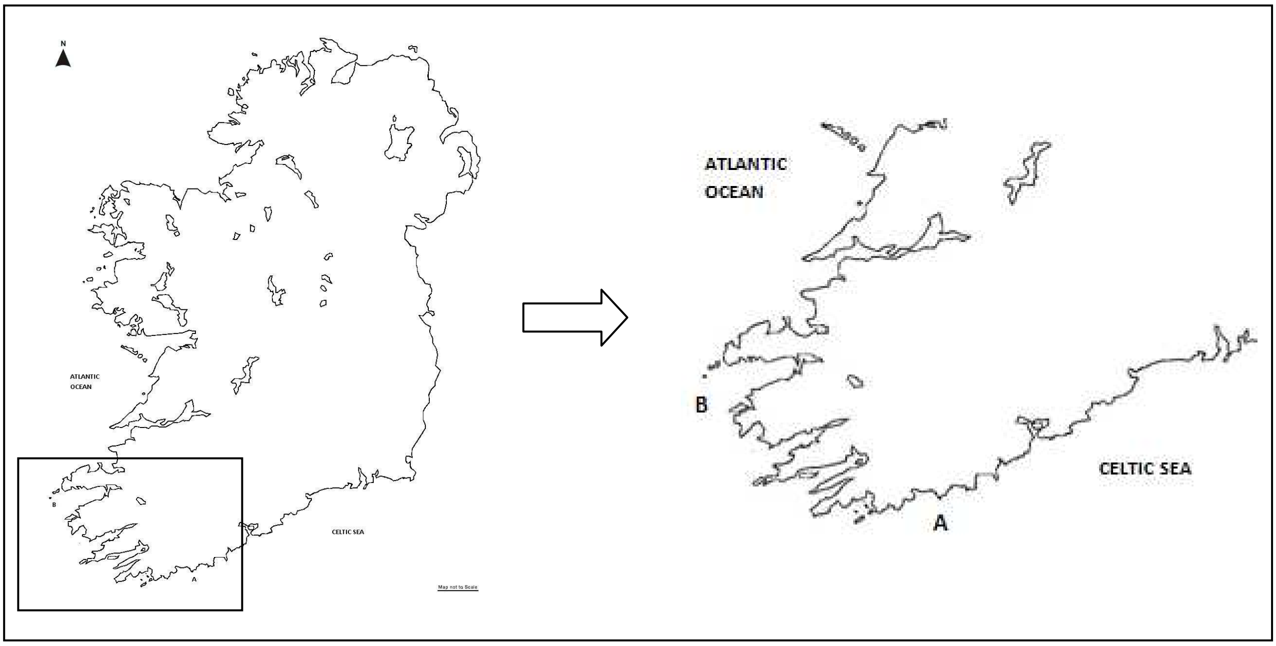

Figure 7. Map of the survey areas; Cork (A) and Blasket (B), (modified from www.wikipedia.org).

All files were recorded by Eugene McKeown from Biospheric Engineering Ltd during daylight (between noon and 4pm) on three different surveys for both locations in 2008.

Two different hydrophones were used. Blasket files were recorded using a Reson TC4032 (**Fig. 8**) while Cork files were recorded using a Cetacean Research C54XRS (**Fig. 9**). Both hydrophones were used due to their high sensitivity, low noise and flat frequency response over a wide frequency range. Although the Cetacean Research C54XRS has a lower linear frequency range (0.016 to 44kHz) that allows the detection of infrasonic, audible and ultrasonic sounds, making it more sensible than the Reson TC4032.

Figure 8. Image of a Reson TC4032 hydrophone (www.reson.com)

Figure 9. Image of a Cetacean Research C54XRS hydrophone (www.cetaceanresearch.com)

Still, the hydrophones were not chosen for this reason but because they were available at the moment of the recordings.

These recordings were done randomly and therefore no visual observations are available. The number of individuals as well as their distance from the boat is unknown.

2.2 Computer Analysis

Spectrographic Analysis

A combination of two programmes, **Adobe Audition** version 1.5 (**Adobe Systems Incorporated**) and **MATLAB** version 7.4 (R2007a), (**The MathWorks, Inc.**), were used to analyse the whistles. The recordings were first played using Adobe Audition. Only clear whistles were considered for counting. Whistles were considered clear when they were easily detected aurally and by visual inspection of the spectrogram (Oswald *et al.*, 2003).

Before working on the data, a discrete fast Fourier transform (FFT) was carried out on the Blasket Islands data to remove the background noise. No FFT was undertaken for the Cork data due to low level of background noise on the files. Each clear individual whistle was extracted using Adobe Audition Marquee Selection Tool and then copied to a new file.

Once all the clear whistles were extracted and copied into a new file, the whistles could then be imported into Matlab. Two Matlab scripts given by John Cunningham were used; one to filter all the files and smooth out the still remaining noise, and the other to create a spectrogram of each whistle. Eight variables were measured from each whistle (**Fig. 10**): (1) duration (s), (2) start frequency (Hz), (3) end frequency (Hz), (4) minimum frequency (Hz), (5) maximum frequency (Hz), (6) number of inflections points (defined as a change from positive to negative or negative to positive slope), (Oswald *et al.*, 2003; Ansmann, 2005), (7) number of harmonics and (8) number of steps (defined as a portion of the whistle with zero slope lasting at least 20msec that separates two portions of similar slope), (Oswald *et al.*, 2003; Ansmann, 2005). The data was exported onto an Excel worksheet to proceed with the statistics analysis.

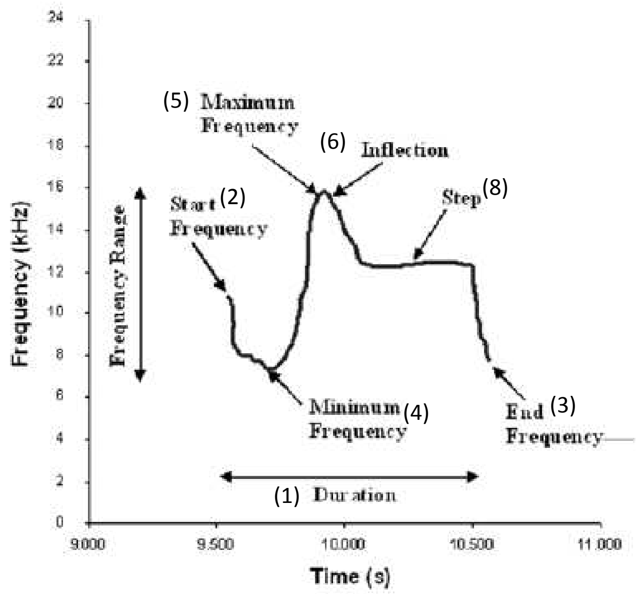

Figure 10. Whistle contour illustrating 7 of the 8 parameters measured (modified from Ansmann, 2005).

Moreover, the whistles were identified and classified according to their contour (**Fig. 11**). Data was also exported onto Excel for further analysis.

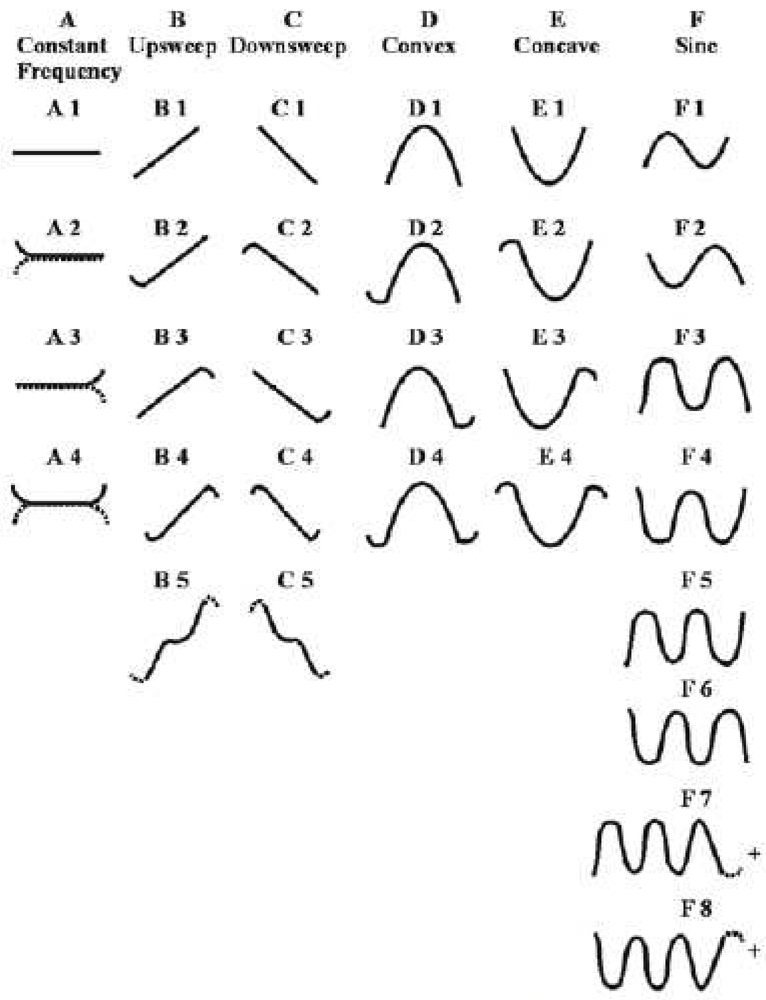

Figure 11. Idealized contour of the different whistle types (Ansmann, 2005).

Statistical Analysis

All statistical tests were carried out using **Minitab** statistical software, version 15 (**Minitab Inc.**).

First of all, the quantitative data was subjected to an Anderson-Darling test for normality in order to decide which statistical test should be used. The Anderson-Darling test for normality is used to test if a sample of data came from a population with a specific distribution (Dytham, 2003). The results show that duration is the only parameter with a normal distribution; therefore we used a parametric method to proceed with the analysis.

The parametric method used was the independent t-test (also known as 2-tailed Student's t-test). The independent t-test can be used to determine whether the means of two independent samples are different enough so that we can conclude that they were taken from different populations (Ashcroft & Pereira, 2003). This method was used given two assumptions; the first assumption is that the samples sizes are different (unpaired) and the second assumption is that both populations have equal variances.

An F-test was previously conducted to assess if our variances were homogeneous.

The remaining parameters of the quantitative data, those not normally distributed, were analyzed using a non-parametric method. The non-parametric method used was the Wilcoxon Rank sum test (also known as Mann-Whitney U test). The Wilcoxon Rank sum test is the non-parametric equivalent of the independent t-test (Dytham, 2003). However, unlike the t-test, the Wilcoxon Rank sum test does not make assumptions about homogeneity of variances or normal distributions (Dytham, 2003).

Also, a level of significance of 95% and the number of degrees of freedom (Df) were calculated. A confidence interval of 95% means that in 95% of occasions the population mean will fall inside the interval, whilst the remaining 5% will fall outside the interval (Rees, 1995) .The numbers of degrees of freedom are defined as the number of values in the final calculation of a statistic that are free to vary (Spiegel & Stephens, 1998).

3. Results

3.1 Cork whistles

During the survey conducted during 2008 off Galley Head in Cork, a total of 1.26hours of recordings were made. From these, it was possible to extract and analyse 282 clear whistles (see **Material and Methods**).

Quantitative method

Eight parameters were measured for the 282 whistles extracted from Cork (see **Appendix I**). The table below shows the minimum, maximum, mean and standard deviation for each parameter.

The shortest whistle lasted 0.089s, while the longest lasted 2.0007s. Both start and maximum frequency ranged from 1540Hz to 27800Hz. End frequency ranged from 4550Hz to 20800Hz. While minimum frequency ranged from 4500Hz to 18800Hz. The maximum number of inflections found was 8, 6 the maximum number of harmonics and 1 the maximum number of steps and 0 being the minimum for all three variables (**Table 1**).

Table 1. Range, mean and standard deviation for the different parameters measured from the Cork whistles.

	Duration (s)	Start Freq (Hz)	End Freq (Hz)	Min Freq (Hz)	Max Freq (Hz)	Inflections	N. of Harmonics	Step
MINIMUM	0.089	4500	4550	4500	8200	0	0	0
MAXIMUM	2.007	27800	20800	18800	27800	8	6	1
MEAN	0.857	13437.589	11004.61	8667.553	17025.709	0.780	0.822	0.046
STD. DEVIATION	0.274	4400.553	3710.895	1871.823	2900.252	1.157	0.741	0.210

Classification method

The whistles were classified, according to Richardson *et al*. (1995), into 6 main shapes and then sub-categorized depending on the degree of modulation from the general type (**Fig. 11**).

Downsweeps were the most common whistle type found with a proportion of 32%, followed by Convex (25%) and Upsweep (19%). Sine type described 14% of the whistles while Concave made up for 8% of the whistles. The least frequent whistle type was Constant Frequency with 2% (**Fig. 12**).

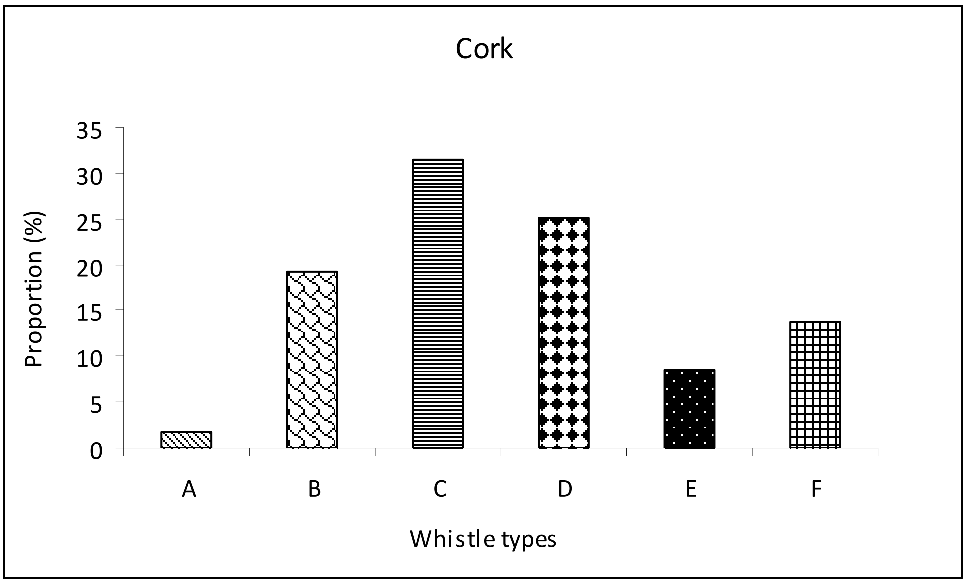

Figure 12. Proportion (%) of the 6 main different whitle types from Cork´s 282 clear whistles.

When the whistles were further classified into sub-categories, it showed that C1 was the most common whistle sub-type with a proportion of 14%, followed by D1, C2 and D3 with 11, 9 and 8%, respectively. The first sub-type was the most frequent for categories C, D and E. The second sub-type was the most frequent for categories B and F. While sub-type 4 was the most frequent for category A (**Fig. 13**).

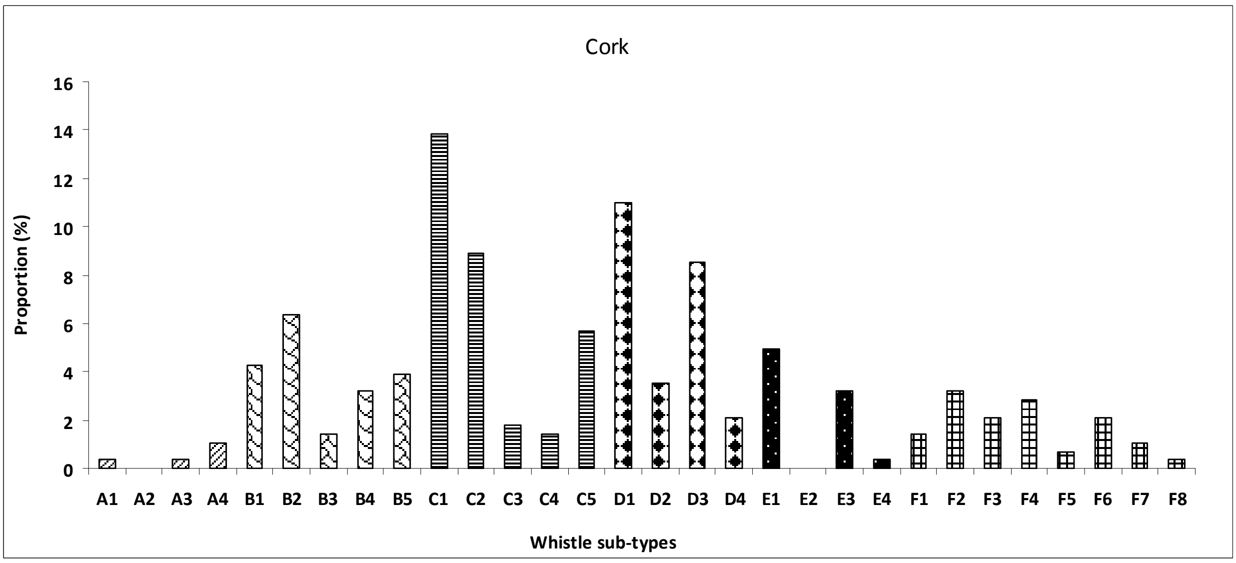

Figure 13. Cork whistles classified into sub-categories.

3.2 Blasket Island whistles

The total time recorded off Blasket Islands in Kerry was 0.73h. 80 clear whistles were visually detected and extracted for the analysis.

Quantitative method

Following the same procedure than with the Cork whistles, eight parameters were measured for the 80 whistles extracted off Blasket Islands (see **Appendix I**). The table below shows the minimum, maximum, mean and standard deviation for each parameter.

The shortest whistle was 0.3964s long, while the longest lasted 1.6484s. Start frequency ranged from 6000Hz to 22000Hz, whereas end frequency ranged from 4500Hz to 20000Hz. Minimum and maximum frequency ranged from 4500Hz to 15400Hz and from 11300Hz to 22000Hz, respectively. The maximum number of inflections was 5, 4 the maximum number of harmonics and 1 the maximum number of steps, whilst 0 was the minimum for all three parameters (**Table 2**).

Table 2. Range, mean and standard deviation for the different parameters measured off Blasket Islands.

	Duration (s)	Start Freq (Hz)	End Freq (Hz)	Min Freq (Hz)	Max Freq (Hz)	Inflections	N. of Harmonics	Step
MINIMUM	0.3964	6000	4500	4500	11300	0	0	0
MAXIMUM	1.6484	22000	20000	15400	22000	5	4	1
MEAN	0.9126	12975	11610	8523.7500	16499.3750	0.6625	1.2750	0.0375
STD. DEVIATION	0.2531	4459.2245	4210.0723	1972.0672	2878.6039	1.0902	0.9675	0.1912

Classification method

The 80 whistles were classified following the same procedure than the Cork whistles. The figure below shows the proportion of each main category.

Downsweep was the most common whistle type with a proportion of 36%, followed by Upsweep with 26%. Sine made up for 18%, while Convex described 15% of the whistles. The two least common types were Constant Frequency (2%) and Concave (3%), (**Fig. 14**).

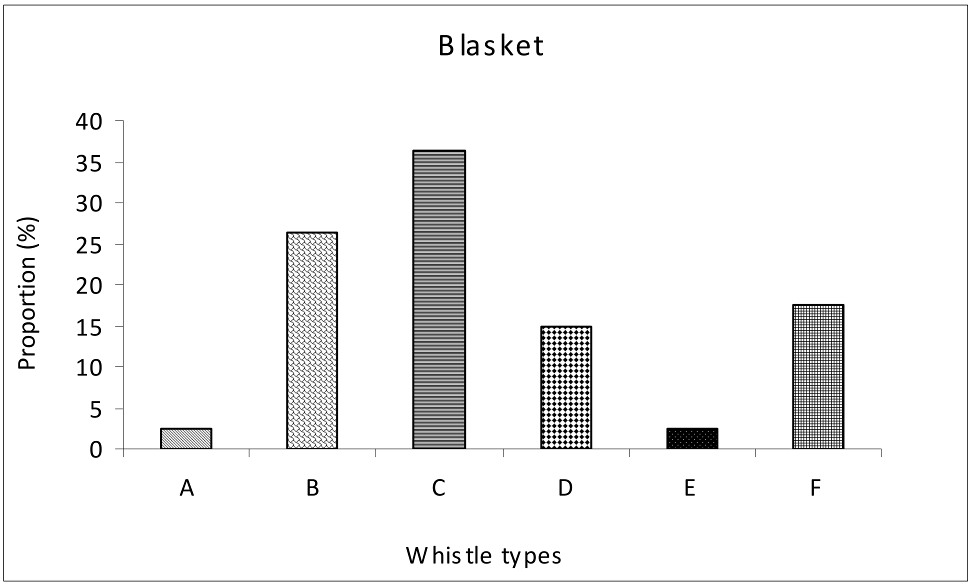

Figure 14. Proportion (%) of each main whistle type for the Blasket Islands whistles.

Breaking the whistles down further, C5 was the most common whistle sub-type with a proportion of 20% followed by C1 which described 14% of the whistles. This was followed by B1, C1 and D1 (16%, 14% and 9%, respectively). The second sub-type was the most common for group F which made up for 6% closely followed by F4 with a proportion of 5%. Also on 5% was D4 with E solely represented by E1 at 3%. Within category A, both A2 and A4 were the only sub-types identified; both with the same proportion of 1% (**Fig. 15**).

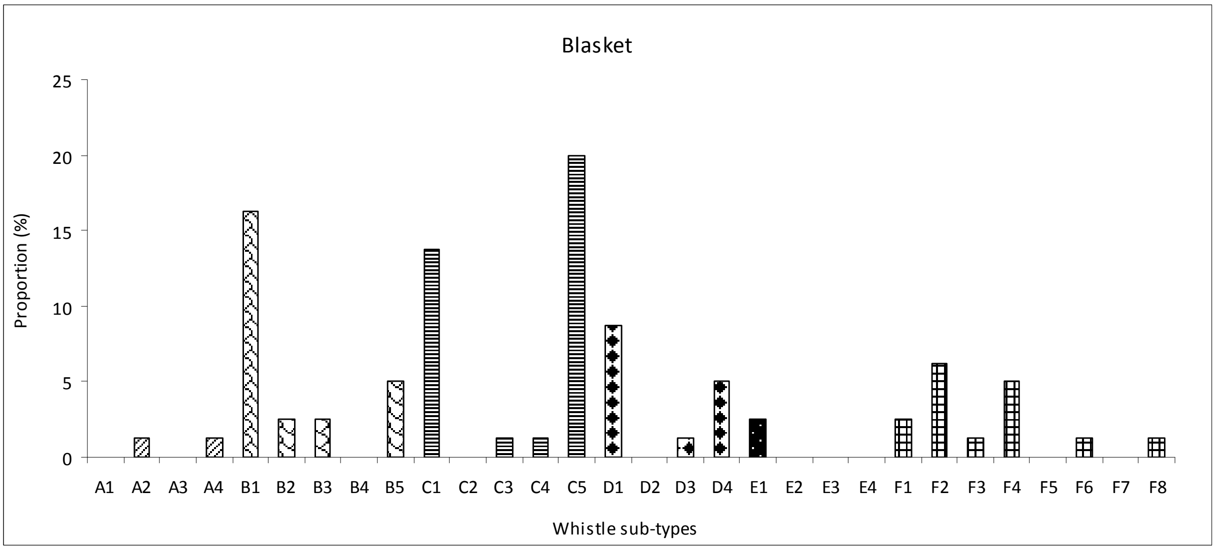

Figure 15. Proportion (%) of each sub-types of whistle for the Blasket Islands whistles.

3.3 Cork whistles vs. Blasket Islands whistles

Quantitative method

The only whistle variable that had a normal distribution was the duration, whereas the rest had a non-parametric distribution (not normally distributed), (see **Appendix II**). Therefore, the duration parameter was tested using a t-test (parametric method) whilst the remaining parameters were tested using a Wilcoxon Rank sum test (non-parametric method) in order to look for significant differences in the means of each variable between both sampling areas. An F-test was used to ascertain whether both locations had equal variances (see **Appendix III**).

No significant differences were found in the means for all the variables (**Fig. 16-23**) except for the number of harmonics (**Fig. 22**), for which the test showed a significant difference between the two locations (t=-4.14; df= 360; p<0.05), (see **Appendix IV**). There were far more harmonics among the Blasket Island whistles than in those recorded off West Cork.

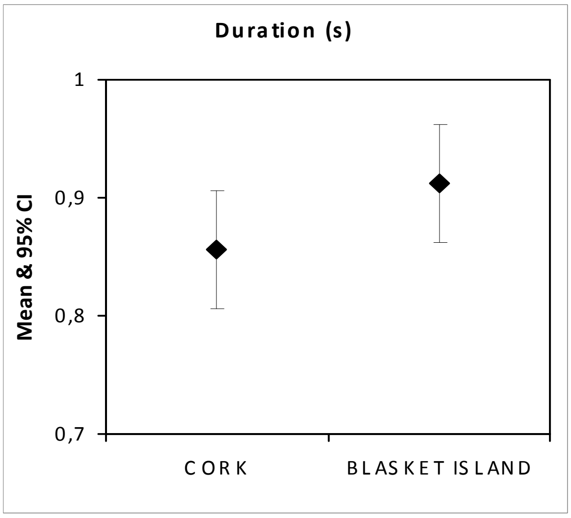

Figure 16. Error bar graph showing mean and 95% CI of duration by location.

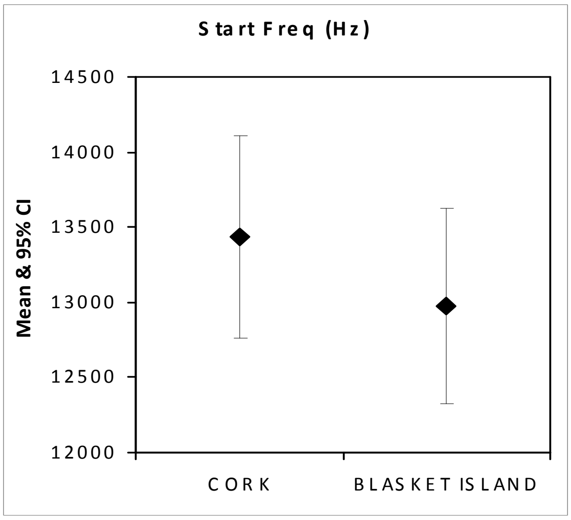

Figure 17. Error bar graph showing mean and 95% CI of start frequency by location.

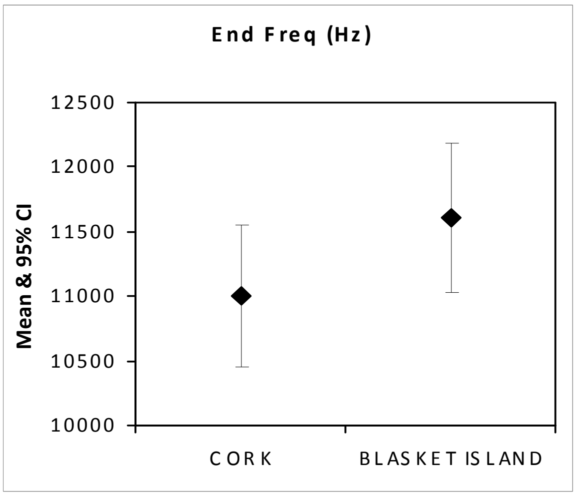

Figure 18. Error bar graph showing mean and 95% CI of end frequency by location.

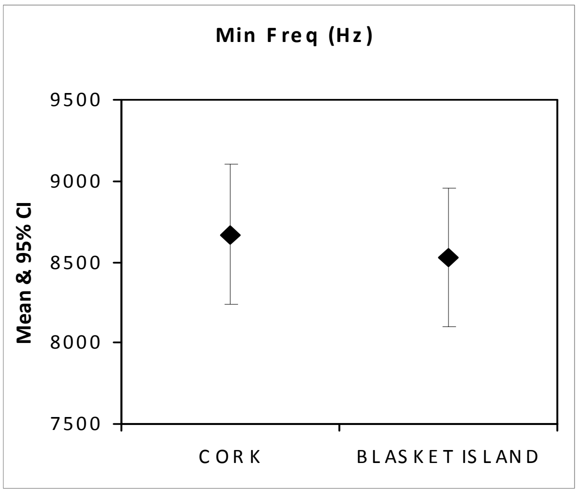

Figure 19. Error bar graph showing mean and 95% CI of minimum frequency by location.

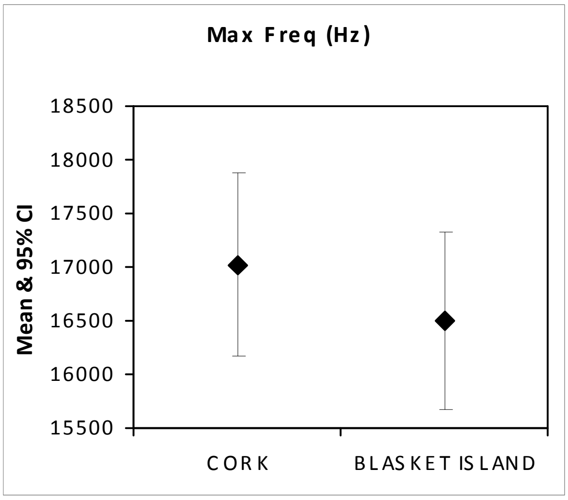

Figure 20. Error bar graph showing mean and 95% CI of maximum frequency by location.

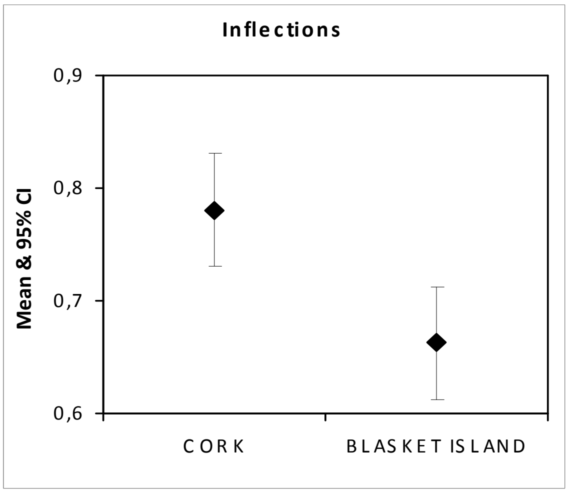

Figure 21. Error bar graph showing mean and 95% CI of inflections by location.

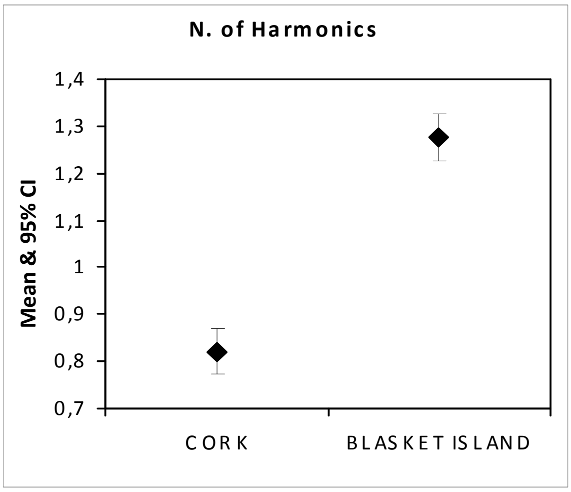

Figure 22. Error bar graph showing mean and 95% CI of number of harmonics by location.

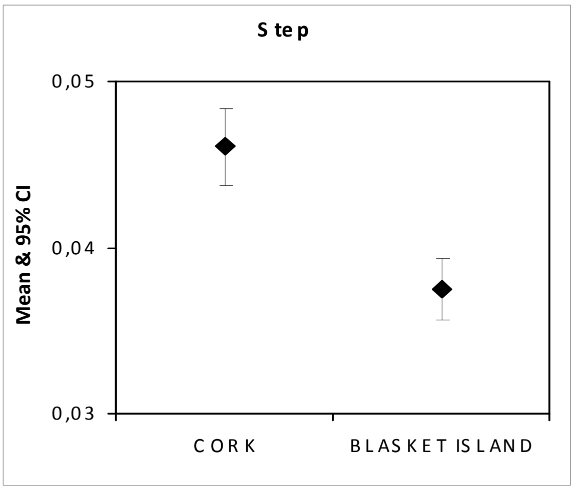

Figure 23. Error bar graph showing mean and 95% CI of step by location.

Classification method

Comparing the whistles extracted from Off Cork with that Off Blasket Island, the following results are obtained.

Downsweep was the most common whistle type for both locations with a proportion of 32% and 36% (Cork and Blasket Islands, respectively). For the Cork whistles, the second and third whistle types were Convex and Upsweep (25% and 19%, respectively). On the other hand, Upsweep was the second most common whistle category for the Blasket whistles which comprised 26% of the whistles, followed by Sine (18%). Constant Frequency was the lowest type described for the two locations (2% Cork and 3% Blasket), (**Fig. 24**).

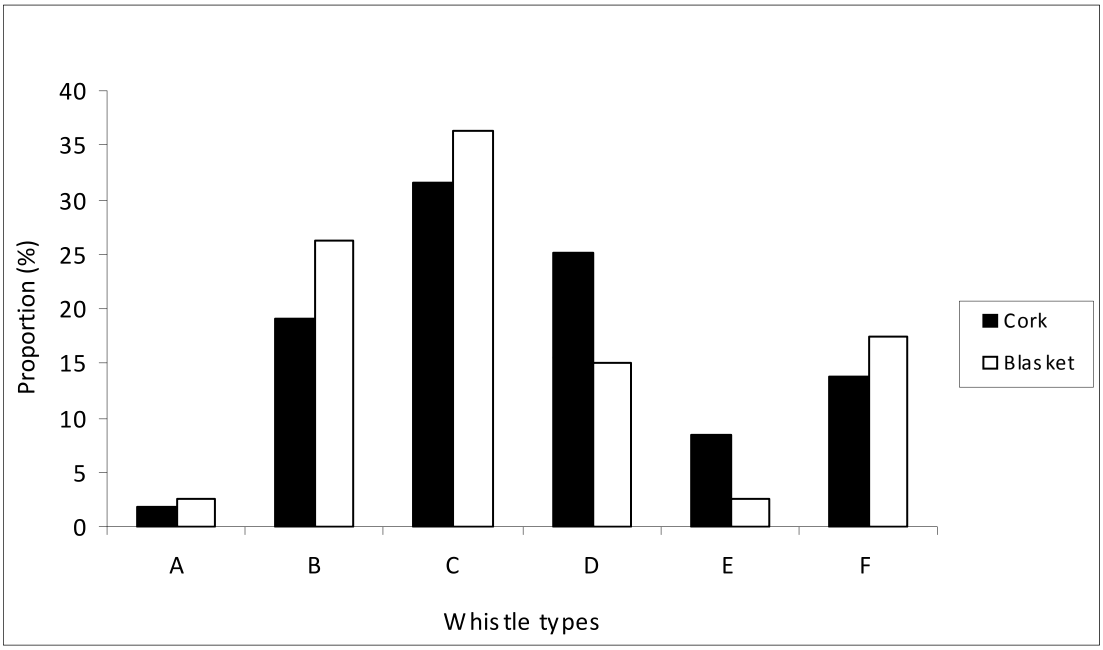

Figure 24. Proportion (%) of overall whistle type from the two locations, Cork whistles (black) and Blasket Islands whistles (white).

Analyzing the whistle's sub-types, there is a slight difference between the whistles from the two areas. Whereas sub-type C5 was the most common for the Blasket whistles with a proportion of 20%, that same sub-type only made up for 6% in the Cork whistles. C1 made up for 14% of the whistle sub-types for both locations. D1 comprised 11% of the Cork whistles, whilst the same sub-type for the Blasket Islands whistles described 9%. B1 made up for 16% on the Blasket Islands whistles,while for the Cork only made up for 4%. In the case of the Cork whistles, C2 and D3 both described 9% of the whistles, whilst the same sub-types for the Blasket whistles only made up for 3% and 1%, respectively. The two least common whistle sub-types according to both locations were Constant Frequency and Concave, (**Fig. 25**).

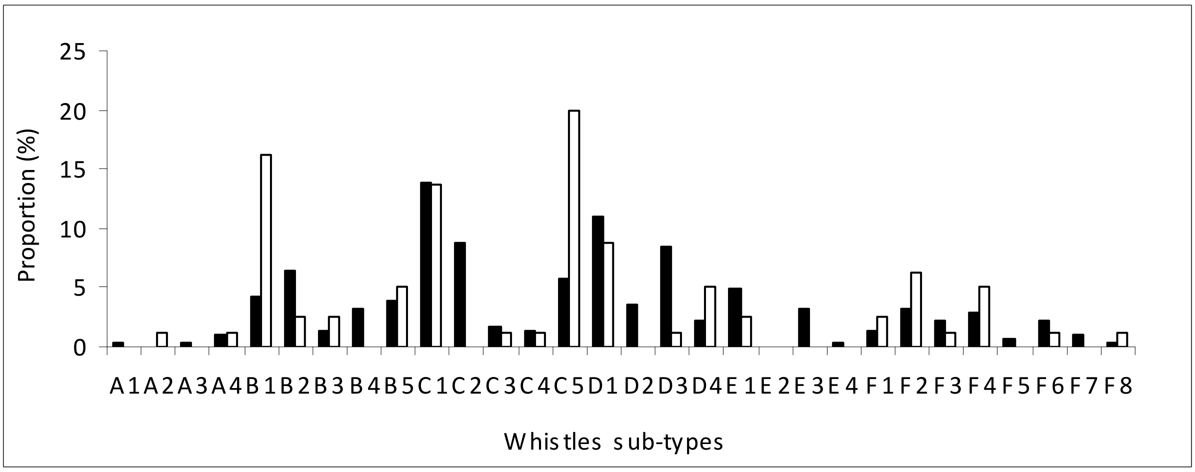

Figure 25. Proportion of each sub-type whistle of the two sampling locations, Cork whistles (black) and Blasket Islands whistles (white).

4. Discussion

4.1 Cork whistles

The 282 clear whistles recorded from common dolphins Off Galley Head in Cork (Celtic Sea) covered a broad frequency range from 1.5kHz to 27.8kHz, with most whistles occurring between 8 and 17kHz. The shortest whistle recorded lasted 0.089s, while the longest lasted 2.0007s with a mean of 0.857s. A maximum number of 8 inflections were found with an average of 0.780. Also, a maximum number of 6 harmonics and 1 step were found with a mean of 0.822 and 0.046, respectively. Downsweep was the most common whistle type found while Constant Frequency was the least (32% and 2%, respectively). The first sub-type was the most frequent for categories C, D and E. The second sub-type was the most frequent for categories B and F. While sub-type 4 was the most frequent for category A.

Results from previous studies showed that most of the common dolphin whistles occur between 20Hz and 20kHz (Richardson *et al*., 1995). In another study in the Celtic Sea, Ansmann *et al*. (2007) found that the frequency of the common dolphin in the Celtic Sea span from 3.56kHz to 23.51kHz, with most whistles occurring between 9 and 15kHz. Moreover, the maximum and minimum duration of the whistles are remarkably similar in both studies. The variations of her results with the results described in this study are practically negligible, and any differences can be attributed to the differences in methodology used. In contrast, in the present study there were found a higher number of inflections as well as harmonics, which shows that the whistles recorded in this study were structurally more complex than those recorded by Ansmann *et al*. (2007). The fact that the simplest whistle sub-types were the most common in her study made her suggest that a large part of the repertoire of common dolphins in the Celtic Sea consisted of non-signature whistles (Ansmann *et al*., 2007).

The general whistle type Upsweep (31%) was the most common reported in Ansmann *et al*. (2007). Downsweep was the second most common type, which made up 26.5% therein (Ansmann *et al*., 2007), followed by Constant Frequency (14.3%). Also Wakefield's (2001) and Scullion's (2004) studies in the Celtic and Irish Seas showed that Upsweep was again the most often recorded type followed by Downsweep and Constant Frequency.

In the present study however Downsweep was the most common type and accounted for 32% of the whistles, followed by Convex (25%) and Upsweep (19%).

4.2 Blasket Island whistles

The 80 clear whistles recorded from common dolphins Off Blasket Islands in Kerry comprised a frequency span from 4.5kHz to 22kHz, with most whistles occurring between 11 and 17kHz. The shortest whistle recorded was 0.3964s long, while the longest lasted 1.6484s with a mean of 0.9126s. A maximum number of 5 inflections were found with an average of 0.663. Also, a maximum number of 4 harmonics and 1 step were found with a mean of 1.275 and 0.0375, respectively. Again, Downsweep was the most common whistle type found (36%), followed by Upsweep and Sine. Constant Frequency and Concave types were the two least common (2% and 3%, respectively). The most common whistle sub-type was C5 with a proportion of 20%. The first sub-type was the most frequent for categories B and D. The second sub-type was the most frequent for group F.

4.3 Cork whistles vs. Blasket Islands whistles

According to Aguilar de Soto *et al*. (2004) there is a north–south gradient in cetacean abundance within Ireland's western continental shelf area, with normally higher numbers of animals detected acoustically in the southern half of Ireland's Atlantic Margin. This gradient appeared to vary, depending on the season (Aguilar de Soto *et al*., 2004). The fact that we found more whistles in Cork (282) than in Blasket Islands (80) may support the north-south gradient reported by Aguilar de Soto *et al*. (2004). However, due to the lack of visual and other background data, we cannot firmly agree with it.

Frequency parameters can help us to discriminate among populations while duration and number of inflections can help us to discriminate within population (Ansmann, 2005). Also, Ansmann *et al*. (2007) reported that variation was greater between populations geographically further apart than among adjacent populations. This variation can be as a result of physiographic and hydrographic characteristics, such as prey distribution, breeding and calving areas and predations, as well as environmental factors (Davisa *et al.*, 2002). Moreover, another parameter that may cause variation in the whistle characteristics is the different behaviour occurring within each dolphin population, such as travelling, socializing, foraging and bow-riding (Ansmann, 2005). Behavioural variation can be shown to lead to differences of parameters such as duration, inflections and steps, because these parameters are affected by the individual's activity at that particular moment (Ansmann, 2005).

The comparison between the short-beaked common dolphins recorded in the two locations found no significant differences in the means of all the parameters with the exception of the number of harmonics. The maximum frequency for the Cork whistles was 27.8kHz whereas the maximum frequency for the Blasket Islands whistles was slightly lower, 22kHz. The minimum frequency was equal for both locations, at 4.5 kHz. On the other hand, the minimum start frequency was 4 times lower in the Cork whistles than in the Blasket Islands whistles (**Table 3**). The means of all 4 frequency parameters for these locations were broadly similar and the fact that no significant differences were found indicates that any variations are minor between the two locations. An unknown factor in each case is the number of individuals that comprise the population. Also the total recording time in each location is relevant as dolphins have to produce sounds over the interval the equipment is deployed in order for whistles to be registered. Thus, it might seem that the Cork population was bigger than Blasket's given that more whistles were recorded per hour there. But it might simply be that they were more vocal off Cork or engaged in an activity that involves more vocalisation. It could also be the case that this is broadly the same population that is migrating, but is less vocal off the Blaskets.

Sea conditions are relevant, as is the social activity e.g. whether simply travelling or foraging. This emphasises the need for comprehensive observational data to accompany each recording session.

The numbers of inflections and steps were a bit higher off Cork than off the Blasket Islands, although not significantly so. The mean number of harmonics obtaining off the Blasket Islands was however significantly different to the mean number off Cork. This nonetheless might be explained by the position of the individual with respect to the equipment: if the individual vocalizes facing the hydrophone, the sound wave that arrives will be of better quality than if the individual is not facing the hydrophone. As well, the distance of the individual with respect to the equipment is a factor here: if the individual is situated near the equipment or within few meters, the signal will be stronger than if the individual is far away and any harmonics in the original sound will likely still remain in evidence. Directionality of the signal with higher frequencies has been reported elsewhere (Lammers & Au, 2003).

Moreover, it has to be considered, that the whistles were recorded randomly using different equipment and without following a pattern, which may have influence the results obtained. The differences in sensibility of the two hydrophones could also explain why there are more whistles in Cork than in the Blasket Islands area.

Table 3. Range, mean and standard deviation for the different parameters measured for the two locations.

	CORK				**BLASKET ISLANDS**			
	Min	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**
Duration (s)	0.089	2.007	0.857	0.274	0.3964	1.6484	0.9126	0.2531
Start Freq (Hz)	4500	27800	13437.589	4400.553	6000	22000	12975	4459.225
End Freq (Hz)	4550	20800	11004.61	3710.895	4500	20000	11610	4210.072
Min Freq (Hz)	4500	18800	8667.553	1871.553	4500	15400	8523.75	1972.067
Max Freq (Hz)	8200	27800	17025.71	2900.252	11300	22000	16499.38	2878.604
Inflections	0	8	0.78	1.157	0	5	0.6625	1.0902
N. of Harmonics*	0	6	0.822	0.741	0	4	1.275	0.9675
Step	0	1	0.046	0.21	0	1	0.0375	0.1912

Downsweep was the most common whistle overall type for both locations. Moreover, the first and second sub-types were the most common in both locations which agree with the results obtained by Ansmann *et al*. (2007), and consequently we may suggest that the whistles recorded in this study consisted of non-signature whistles.

5. Conclusion and Future research

The island of Ireland and its Exclusive Economic Zone (EEZ) comprise a wide variety of cetacean and seabird species (Aguilar de Soto *et al*., 2004), making this area one of the most important cetacean habitats in Europe (Wall, 2007). Acoustic methods greatly enhance information on cetacean distribution versus visual surveys alone (Aguilar de Soto *et al*., 2004), but still nowadays it is very difficult to identify the whistles of an individual from a pod of dolphins and therefore this has to be considered when examining the results (Ansmann et al., 2007).

This study has proven that acoustic monitoring alone does not provide enough information regarding short-beaked common dolphin populations; therefore the need for a combined approach with visual data is of great importance to improve future research on this area. Nonetheless it has been demonstrated that acoustic methods increase the efficiency of offshore surveys (Lewis *et al*., 1998; Mellinger *et al*., 2007) especially where visual surveys are not feasible. Furthermore the implementation of new techniques will greatly enhance species classification and thus researchers will be able to study temporal and spatial distribution, as well as abundance patterns, of Delphinids (Hildebrand, 2007).

In the present study no significant differences were found among locations. Therefore it can lead us to conclude that either they were the same population that moves in search for food or two different populations so close geographically and/or genetically that no variations can be detected. Also in both locations, the dolphins were feeding, so it may well be that common dolphin populations show similar whistle characteristics while feeding. Finally no signature-whistles were identified.

To conclude, there is not enough data to give a broad view of the short-beaked common dolphin populations that inhabit the south and southwest waters of Ireland. Hence a more detailed and extensive study with more elaborate methodology needs to be implemented in order to answer all the questions raised in this study.

6. References

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7. Appendix

7.1 Appendix I

Table 4. Cork's 282 whistles types with the calculations for all parameters measured in the spectrographic analysis.

WHISTLE Type	Duration (s)	Start Freq (Hz)	End Freq (Hz)	Min Freq (Hz)	Max Freq (Hz)	Inflections	N. of Harmonics	Step
D1	1.2266	8.55E+03	9.10E+03	8.55E+03	1.84E+04	1	2	1
F3	1.2305	5.50E+03	1.02E+04	5.50E+03	1.35E+04	3	2	0
F4	1.6000	1.35E+04	1.46E+04	8.70E+03	1.51E+04	3	2	1
F4	1.1806	1.70E+04	1.33E+04	8.70E+03	1.70E+04	3	1	0
B2	0.7778	8.00E+03	9.00E+03	6.50E+03	9.20E+03	0	2	0
B2	0.7963	1.12E+04	1.43E+04	1.08E+04	1.45E+04	0	2	0
D3	0.7880	8.60E+03	6.65E+03	6.65E+03	1.31E+04	1	0	0
E3	0.6506	1.34E+04	1.08E+04	7.90E+03	1.34E+04	1	0	0
C4	0.6048	1.12E+04	6.60E+03	6.60E+03	1.12E+04	0	1	0
A3	0.6262	6.20E+03	1.19E+04	6.20E+03	1.19E+04	0	0	0
B4	0.2016	9.50E+03	1.70E+04	9.30E+03	1.70E+04	0	0	0
B5	0.2926	1.10E+04	1.48E+04	8.30E+03	1.48E+04	0	0	0
C5	0.5131	1.21E+04	5.20E+03	5.20E+03	1.21E+04	0	0	0
D1	0.0886	1.36E+04	1.42E+04	1.36E+04	1.46E+04	0	1	0
B5	0.4398	1.05E+04	1.59E+04	1.05E+04	1.59E+04	0	0	0
F7	2.0067	1.03E+04	1.27E+04	7.80E+03	1.83E+04	6	1	0
F3	0.9774	1.31E+04	1.26E+04	9.90E+03	1.83E+04	3	1	0
D3	1.2218	8.40E+03	1.18E+04	8.40E+03	1.80E+04	2	2	0
D3	1.4290	1.40E+04	9.60E+03	9.60E+03	1.78E+04	1	2	0
D1	0.8430	1.02E+04	8.20E+03	8.20E+03	1.80E+04	1	2	0
D3	0.6689	9.00E+03	6.30E+03	6.30E+03	1.44E+04	1	2	0
C2	0.6995	1.25E+04	8.70E+03	1.40E+04	8.70E+03	0	0	0
E3	0.9133	1.50E+04	1.46E+04	9.00E+03	1.50E+04	1	1	0
B1	0.6818	1.15E+04	1.36E+04	1.14E+04	1.36E+04	0	0	0
D1	0.6359	1.22E+04	1.30E+04	1.22E+04	1.61E+04	1	1	0
E3	0.5860	1.80E+04	2.00E+04	1.37E+04	2.00E+04	1	2	0
C5	0.7564	2.78E+04	1.88E+04	1.88E+04	2.78E+04	0	1	0
C5	1.0920	1.92E+04	9.70E+03	8.20E+03	1.92E+04	0	2	0
E1	0.9535	1.60E+04	1.63E+04	9.40E+03	1.63E+04	1	1	0
B2	0.5913	1.36E+04	1.53E+04	9.30E+03	1.53E+04	0	1	0
D1	0.1485	1.50E+04	1.62E+04	1.50E+04	1.73E+04	0	1	0
F4	0.7375	1.35E+04	1.31E+04	7.00E+03	1.35E+04	3	0	1
B4	0.2881	1.20E+04	1.45E+04	1.20E+04	1.50E+04	0	1	0
C2	0.9545	1.08E+04	7.60E+03	7.60E+03	1.62E+04	0	2	0
D1	0.4542	8.50E+03	1.07E+04	8.50E+03	1.52E+04	1	0	0
E1	0.7455	1.90E+04	1.88E+04	1.14E+04	1.90E+04	1	1	0
C4	0.6043	1.08E+04	9.00E+03	9.00E+03	1.08E+04	0	1	0
B2	0.7006	6.00E+03	1.53E+04	6.00E+03	1.53E+04	0	0	0
D3	1.2425	1.06E+04	8.20E+03	1.33E+04	8.20E+03	1	3	0
F5	1.4571	1.04E+04	1.14E+04	8.40E+03	1.80E+04	4	1	0

F5	1.1126	1.30E+04	1.23E+04	8.35E+03	1.60E+04	4	2	0
D2	1.2749	7.00E+03	9.60E+03	7.00E+03	1.99E+04	1	2	0
B1	1.0587	9.00E+03	1.88E+04	7.50E+03	1.88E+04	0	2	0
E1	0.7017	1.10E+04	1.35E+04	8.15E+03	1.35E+04	1	3	0
B2	0.7098	1.30E+04	1.45E+04	7.00E+03	1.45E+04	0	2	0
B4	0.8366	9.00E+03	1.72E+04	8.60E+03	1.72E+04	0	2	0
B4	1.0592	6.40E+03	1.64E+04	6.40E+03	1.64E+04	0	3	0
D2	1.1966	1.30E+04	9.90E+03	8.00E+03	1.80E+04	1	2	0
F4	0.7862	1.56E+04	7.70E+03	6.50E+03	1.56E+04	3	2	0
B2	1.0431	1.20E+04	1.66E+04	7.45E+03	1.66E+04	0	2	0
F7	1.4721	1.04E+04	1.39E+04	8.90E+03	1.73E+04	8	0	0
D3	0.7338	1.25E+04	7.80E+03	7.80E+03	1.68E+04	1	1	1
B4	0.6848	7.10E+03	1.65E+04	7.10E+03	1.65E+04	0	2	0
B5	0.9718	1.10E+04	1.72E+04	8.80E+03	1.72E+04	0	2	0
B1	0.4966	9.60E+03	1.30E+04	9.60E+03	1.30E+04	0	2	0
B1	0.2214	8.00E+03	9.50E+03	8.00E+03	9.50E+03	0	3	0
B1	0.2098	7.50E+03	8.30E+03	7.50E+03	8.30E+03	0	3	0
B2	0.6949	1.20E+04	1.48E+04	9.60E+03	1.48E+04	0	2	0
B2	0.7700	1.20E+04	1.55E+04	9.60E+03	1.55E+04	0	2	0
C2	0.5144	1.22E+04	1.12E+04	1.12E+04	1.25E+04	0	1	0
D3	1.0331	1.30E+04	1.10E+04	1.10E+04	1.95E+04	1	2	0
C2	0.4490	1.50E+04	8.30E+03	8.30E+03	1.62E+04	0	2	0
B5	0.9457	7.50E+03	1.30E+04	7.50E+03	2.08E+04	0	6	0
B5	0.8531	1.00E+04	1.72E+04	8.20E+03	1.78E+04	2	4	0
B5	0.4575	6.00E+03	1.40E+04	6.00E+03	1.40E+04	0	1	0
C1	1.0938	1.90E+04	7.40E+03	7.40E+03	1.90E+04	0	1	0
C1	0.9545	2.00E+04	8.60E+03	8.60E+03	2.00E+04	0	1	0
C1	1.0801	2.02E+04	8.10E+03	8.10E+03	2.02E+04	0	1	0
C1	0.6107	2.08E+04	9.40E+03	9.40E+03	2.08E+04	0	1	0
C1	1.0298	1.92E+04	8.65E+03	8.65E+03	1.92E+04	0	1	0
C2	0.8901	2.08E+04	8.80E+03	8.80E+03	2.08E+04	0	1	0
C2	1.0506	1.95E+04	9.20E+03	9.20E+03	1.95E+04	0	1	0
C1	1.0836	1.90E+04	7.20E+03	7.20E+03	1.90E+04	0	1	0
E1	0.7894	1.90E+04	1.06E+04	8.90E+03	1.90E+04	1	1	0
B3	0.7677	1.16E+04	1.61E+04	1.12E+04	1.85E+04	0	0	0
C1	1.1868	2.05E+04	7.80E+03	7.80E+03	2.05E+04	0	1	0
D3	1.3308	9.20E+03	9.20E+03	9.20E+03	1.70E+04	1	1	1
D1	0.8827	1.10E+04	8.50E+03	8.50E+03	1.55E+04	1	1	0
C2	0.8567	1.35E+04	6.80E+03	6.80E+03	1.56E+04	0	1	0
C2	0.8604	1.20E+04	6.50E+03	6.50E+03	1.53E+04	0	1	0
C1	0.9198	2.00E+04	8.80E+03	8.65E+03	2.00E+04	0	1	0
C1	0.3746	1.55E+04	1.03E+04	1.03E+04	1.55E+04	0	0	0
B1	0.8493	9.00E+03	1.50E+04	8.70E+03	1.50E+04	0	1	0
F1	0.8196	1.40E+04	1.30E+04	8.50E+03	1.46E+04	2	1	0
C2	0.7529	1.25E+04	7.00E+03	7.00E+03	1.47E+04	0	1	0
C2	0.6713	1.36E+04	6.80E+03	6.80E+03	1.48E+04	0	1	0
C2	0.4376	1.40E+04	1.06E+04	1.06E+04	1.56E+04	0	0	0
C2	0.7047	1.45E+04	7.20E+03	7.20E+03	1.54E+04	0	1	0
F2	0.8306	2.05E+04	1.40E+04	1.31E+04	2.05E+04	2	0	0
B5	1.1571	8.70E+03	1.98E+04	8.70E+03	1.98E+04	0	1	0
D2	1.2239	1.12E+04	8.50E+03	8.50E+03	1.76E+04	1	1	0

B3	0.5341	1.17E+04	1.68E+04	1.17E+04	1.84E+04	0	0	0
C1	0.7529	1.90E+04	9.10E+03	9.10E+03	1.90E+04	0	1	0
B3	0.8678	1.10E+04	1.79E+04	1.10E+04	1.91E+04	0	0	0
D1	1.2387	8.50E+03	7.20E+03	7.20E+03	1.60E+04	1	1	0
C2	0.6972	1.85E+04	8.00E+03	8.00E+03	1.90E+04	0	0	0
C2	0.7257	1.96E+04	8.50E+03	8.50E+03	1.96E+04	0	1	0
C2	0.6919	1.86E+04	1.04E+04	1.04E+04	1.88E+04	0	0	0
D3	1.3351	8.80E+03	6.50E+03	6.50E+03	1.69E+04	1	0	1
C1	1.1386	1.85E+04	7.50E+03	7.50E+03	1.85E+04	0	1	0
C2	0.8604	1.92E+04	9.80E+03	9.80E+03	1.94E+04	0	1	0
C1	0.7593	1.97E+04	8.50E+03	8.50E+03	1.97E+04	0	1	0
C1	0.6598	1.92E+04	8.50E+03	8.50E+03	1.92E+04	0	1	0
C1	0.6231	1.91E+04	8.50E+03	8.50E+03	1.91E+04	0	1	0
C2	0.6659	1.85E+04	9.20E+03	9.20E+03	1.88E+04	0	0	0
E1	0.7380	1.50E+04	1.65E+04	9.70E+03	1.65E+04	1	0	0
C3	0.8641	1.55E+04	7.00E+03	5.60E+03	1.55E+04	0	0	0
C5	0.5303	1.95E+04	8.60E+03	8.60E+03	1.95E+04	0	0	0
C5	0.5860	1.92E+04	9.50E+03	9.50E+03	1.92E+04	0	0	0
C5	0.6564	1.90E+04	9.90E+03	9.70E+03	1.92E+04	0	0	0
C1	0.7603	1.95E+04	9.00E+03	9.00E+03	1.95E+04	0	1	0
C5	0.6676	1.95E+04	8.50E+03	8.50E+03	1.95E+04	0	0	0
C5	1.0163	1.55E+04	4.55E+03	4.55E+03	1.57E+04	0	0	0
C5	0.6828	1.93E+04	9.60E+03	9.60E+03	1.93E+04	0	0	0
C5	0.7816	1.94E+04	8.60E+03	8.60E+03	1.94E+04	0	1	0
C2	0.8178	1.95E+04	8.15E+03	8.15E+03	1.98E+04	0	1	0
C2	0.7009	1.94E+04	8.50E+03	8.50E+03	1.94E+04	0	1	0
C1	0.6280	2.00E+04	8.00E+03	8.00E+03	2.00E+04	0	1	0
C1	0.7260	2.00E+04	8.00E+03	8.00E+03	2.00E+04	0	1	0
C1	0.5841	2.00E+04	8.00E+03	8.00E+03	2.00E+04	0	1	0
C1	0.9930	1.98E+04	8.20E+03	8.20E+03	1.98E+04	0	1	0
C1	0.5341	1.92E+04	8.20E+03	8.20E+03	1.92E+04	0	1	0
C1	0.6759	1.94E+04	8.00E+03	8.00E+03	1.94E+04	0	1	0
C1	0.6759	1.90E+04	8.50E+03	8.50E+03	1.90E+04	0	1	0
B4	0.5674	6.25E+03	1.25E+04	6.20E+03	2.00E+04	0	1	0
C1	0.6342	2.00E+04	9.80E+03	9.80E+03	2.00E+04	0	1	0
C2	0.8391	1.35E+04	6.50E+03	6.50E+03	1.56E+04	0	1	0
C2	0.7872	1.30E+04	6.60E+03	6.60E+03	1.45E+04	0	1	0
C2	0.7594	1.50E+04	6.60E+03	6.60E+03	1.59E+04	0	1	0
A4	0.8178	1.42E+04	1.65E+04	1.16E+04	1.65E+04	0	0	0
C2	0.8512	1.35E+04	6.50E+03	6.50E+03	1.55E+04	0	1	0
F2	1.5020	1.80E+04	1.24E+04	1.15E+04	2.02E+04	2	0	0
C1	0.7594	2.05E+04	8.50E+03	8.50E+03	2.05E+04	0	1	0
C1	0.7844	2.03E+04	8.50E+03	8.50E+03	2.03E+04	0	1	0
C1	0.6759	1.96E+04	8.40E+03	8.40E+03	1.96E+04	0	1	0
F2	0.6137	6.70E+03	1.20E+04	6.60E+03	1.63E+04	2	1	0
C1	0.6982	1.93E+04	8.10E+03	8.10E+03	1.93E+04	0	1	0
C1	0.5898	1.84E+04	8.00E+03	8.00E+03	1.84E+04	0	1	0
F4	1.0264	1.80E+04	1.40E+04	9.00E+03	1.80E+04	3	0	0
F6	1.0931	1.72E+04	9.20E+03	8.80E+03	1.72E+04	4	1	0
F2	0.9179	1.65E+04	9.60E+03	8.80E+03	1.65E+04	2	1	0
F6	1.1349	1.65E+04	1.15E+04	9.00E+03	1.65E+04	4	0	0

F4	1.1265	1.86E+04	1.38E+04	9.00E+03	1.86E+04	3	1	0
F2	1.0391	1.70E+04	8.60E+03	8.60E+03	1.70E+04	2	1	1
C1	0.6812	2.05E+04	7.50E+03	7.50E+03	2.05E+04	0	1	0
F6	1.4724	1.25E+04	8.75E+03	8.40E+03	1.82E+04	4	1	0
D4	0.3160	8.00E+03	1.00E+04	8.00E+03	1.38E+04	1	1	0
B1	0.6623	8.50E+03	1.18E+04	8.50E+03	1.18E+04	0	1	0
B2	0.9351	7.50E+03	1.25E+04	7.50E+03	1.28E+04	0	1	0
B2	1.0779	6.00E+03	1.20E+04	6.00E+03	1.20E+04	0	1	0
F6	0.9870	1.35E+04	9.10E+03	9.10E+03	1.80E+04	4	1	0
B3	1.0216	6.00E+03	1.15E+04	6.00E+03	1.15E+04	0	0	0
B5	0.9740	5.85E+03	1.14E+04	5.85E+03	1.55E+04	1	0	0
C2	0.6580	1.50E+04	1.12E+04	1.12E+04	1.64E+04	0	0	0
D3	1.1342	1.20E+04	8.40E+03	8.40E+03	2.08E+04	1	0	0
D3	1.0346	1.38E+04	9.20E+03	9.20E+03	2.10E+04	1	0	0
C1	0.5368	1.23E+04	7.30E+03	7.30E+03	1.23E+04	0	1	0
D1	1.0000	1.22E+04	1.00E+04	1.00E+04	2.09E+04	1	0	0
D1	1.0333	1.30E+04	8.60E+03	8.60E+03	2.05E+04	1	0	0
B1	0.8052	8.40E+03	1.76E+04	8.40E+03	1.76E+04	0	1	0
E1	0.6017	1.40E+04	1.60E+04	1.12E+04	1.60E+04	1	0	0
D1	1.1169	1.00E+04	8.00E+03	8.00E+03	2.15E+04	1	1	0
C4	0.5152	1.80E+04	9.20E+03	9.20E+03	1.80E+04	0	1	0
D1	1.1299	1.05E+04	7.80E+03	7.80E+03	2.06E+04	1	1	0
D3	1.1299	1.10E+04	8.50E+03	8.50E+03	2.05E+04	1	0	0
B1	0.6017	1.15E+04	1.76E+04	1.15E+04	1.76E+04	0	0	0
F3	1.3409	1.40E+04	1.22E+04	9.75E+03	2.02E+04	3	1	0
D4	0.9740	1.05E+04	8.20E+03	8.20E+03	1.40E+04	1	1	0
B4	1.0500	1.10E+04	1.25E+04	8.60E+03	1.48E+04	0	1	1
C1	0.7359	1.90E+04	6.00E+03	6.00E+03	1.90E+04	0	0	0
B4	0.9610	1.05E+04	1.10E+04	8.60E+03	1.51E+04	0	1	0
D3	1.3068	1.40E+04	7.90E+03	7.00E+03	2.10E+04	1	1	0
D3	0.9957	1.00E+04	8.50E+03	8.50E+03	1.65E+04	1	1	0
E1	0.6840	1.13E+04	1.75E+04	1.13E+04	1.93E+04	1	0	0
C5	0.4919	1.36E+04	7.20E+03	7.20E+03	1.36E+04	0	1	0
B5	0.6061	1.30E+04	2.08E+04	1.30E+04	2.08E+04	0	0	0
F2	1.1169	9.00E+03	1.00E+04	8.80E+03	1.77E+04	2	0	0
D1	0.8528	9.60E+03	8.50E+03	8.50E+03	1.42E+04	1	1	0
C5	1.1143	1.96E+04	1.30E+04	1.12E+04	1.96E+04	0	0	0
D2	0.8286	7.60E+03	9.90E+03	7.60E+03	1.46E+04	1	1	0
F4	1.1818	1.50E+04	1.10E+04	8.20E+03	1.51E+04	3	1	0
C3	1.2000	1.96E+04	1.40E+04	1.17E+04	1.96E+04	0	0	0
D1	0.7446	8.00E+03	6.50E+03	6.50E+03	1.42E+04	1	0	0
C1	1.1342	1.80E+04	6.80E+03	6.80E+03	1.80E+04	0	0	0
C1	0.5628	1.70E+04	8.20E+03	8.20E+03	1.70E+04	0	0	0
C1	0.9480	1.90E+04	8.50E+03	8.50E+03	1.90E+04	0	0	0
E3	0.9437	1.75E+04	1.73E+04	1.00E+04	1.75E+04	1	0	0
C1	0.9697	2.00E+04	8.40E+03	8.40E+03	2.00E+04	0	0	0
D3	0.7186	9.00E+03	6.60E+03	6.60E+03	1.34E+04	1	0	0
D2	0.6277	9.70E+03	9.30E+03	9.30E+03	1.65E+04	1	1	0
B1	0.7486	1.56E+04	9.00E+03	9.00E+03	1.74E+04	0	1	0
D1	0.5791	1.15E+04	7.50E+03	7.50E+03	1.85E+04	1	0	0
D4	1.1700	8.00E+03	9.80E+03	7.00E+03	1.52E+04	1	1	0

D2	1.0432	7.50E+03	1.02E+04	7.40E+03	1.40E+04	1	0	0
D3	0.7404	8.00E+03	6.50E+03	6.50E+03	1.43E+04	1	1	0
D1	0.5861	8.60E+03	8.00E+03	8.00E+03	1.38E+04	1	1	0
B1	0.4769	1.00E+04	1.37E+04	1.00E+04	1.37E+04	0	0	0
E3	0.9306	1.60E+04	1.50E+04	8.30E+03	1.60E+04	1	1	0
E1	0.3088	1.47E+04	9.00E+03	6.60E+03	1.47E+04	1	1	0
F3	1.1752	6.60E+03	9.70E+03	6.60E+03	1.33E+04	3	0	0
C1	0.7765	1.69E+04	1.37E+04	1.37E+04	1.69E+04	0	0	0
E1	0.3584	1.30E+04	1.26E+04	6.85E+03	1.30E+04	1	1	0
F3	0.8229	8.70E+03	9.50E+03	8.70E+03	1.39E+04	3	1	0
B2	0.7232	9.90E+03	1.74E+04	9.00E+03	1.74E+04	0	0	0
D1	0.8416	9.80E+03	5.60E+03	5.60E+03	1.57E+04	1	1	0
C3	0.6401	1.33E+04	1.15E+04	7.20E+03	1.33E+04	0	1	0
D4	0.9439	1.02E+04	1.00E+04	1.00E+04	1.68E+04	1	0	0
F3	0.8000	9.40E+03	1.05E+04	9.00E+03	1.38E+04	3	0	0
A1	0.5536	1.10E+04	1.03E+04	1.03E+04	1.10E+04	0	0	0
D1	0.9076	1.14E+04	9.50E+03	9.50E+03	1.96E+04	1	1	0
D2	0.7032	1.15E+04	1.10E+04	1.10E+04	1.97E+04	1	0	0
B2	0.7069	6.50E+03	1.32E+04	6.50E+03	1.32E+04	0	1	0
B1	0.8303	9.50E+03	1.88E+04	9.50E+03	1.88E+04	0	1	0
F2	1.1744	1.60E+04	8.60E+03	8.60E+03	1.63E+04	2	1	0
D1	0.4370	1.00E+04	1.00E+04	1.00E+04	1.80E+04	1	1	0
B5	0.7218	8.50E+03	1.45E+04	8.50E+03	1.55E+04	0	1	0
A4	0.6834	1.00E+04	8.30E+03	8.30E+03	1.00E+04	0	1	0
F6	0.9122	1.80E+04	7.50E+03	7.50E+03	1.80E+04	4	0	0
D1	0.6664	1.32E+04	1.00E+04	1.00E+04	2.07E+04	1	1	0
E1	0.8008	2.15E+04	1.50E+04	8.70E+03	1.50E+04	1	1	0
D1	0.8037	9.20E+03	8.50E+03	8.50E+03	1.55E+04	1	0	0
F6	0.9679	1.96E+04	1.95E+04	1.11E+04	2.03E+04	4	1	0
C1	0.7656	9.50E+03	5.20E+03	5.20E+03	9.50E+03	0	1	0
C1	0.5280	1.85E+04	9.50E+03	9.50E+03	1.85E+04	0	1	0
D3	0.9679	1.05E+04	5.40E+03	5.40E+03	1.56E+04	1	1	0
C5	1.0765	1.95E+04	5.85E+03	5.85E+03	1.95E+04	0	1	0
A4	0.7245	1.10E+04	9.40E+03	9.40E+03	1.29E+04	0	1	0
D2	1.1322	1.55E+04	8.00E+03	8.00E+03	1.51E+04	1	0	0
B2	0.8389	9.40E+03	1.67E+04	9.40E+03	1.67E+04	0	1	0
D2	0.5720	1.18E+04	1.31E+04	1.18E+04	1.66E+04	1	0	0
B5	0.7392	8.50E+03	1.81E+04	8.50E+03	1.81E+04	0	1	0
C5	0.9826	1.90E+04	6.50E+03	6.50E+03	1.90E+04	0	1	0
C5	1.0647	1.88E+04	7.20E+03	7.20E+03	1.88E+04	0	1	0
D4	1.1417	7.65E+03	9.90E+03	7.65E+03	1.75E+04	1	1	1
C5	1.3522	7.60E+03	5.50E+03	5.50E+03	1.54E+04	0	1	0
C1	0.9621	2.05E+04	1.11E+04	1.11E+04	2.05E+04	0	0	0
D1	0.9005	1.21E+04	9.20E+03	9.20E+03	1.98E+04	1	0	0
C3	0.9210	1.45E+04	1.34E+04	9.10E+03	1.45E+04	0	1	0
D1	1.0002	1.18E+04	8.60E+03	8.60E+03	2.00E+04	1	0	0
B2	0.5413	1.00E+04	1.52E+04	1.00E+04	1.52E+04	0	0	0
F1	1.0618	1.20E+04	1.47E+04	1.20E+04	1.53E+04	2	1	0
D1	0.9151	1.18E+04	7.20E+03	7.20E+03	2.04E+04	1	1	0
D1	1.3182	1.00E+04	9.90E+03	6.10E+03	1.89E+04	1	0	0
D3	1.0647	1.00E+04	6.00E+03	6.00E+03	1.54E+04	1	1	1

F4	0.7098	1.65E+04	1.30E+04	9.20E+03	1.65E+04	3	1	0
E1	0.9269	2.16E+04	2.05E+04	1.37E+04	2.16E+04	1	0	0
D3	1.0743	1.20E+04	8.20E+03	8.20E+03	2.06E+04	1	0	0
D3	0.8979	1.26E+04	1.08E+04	1.08E+04	2.00E+04	1	0	0
B2	0.7214	9.60E+03	1.90E+04	9.30E+03	1.90E+04	0	1	0
B2	0.8148	1.00E+04	1.75E+04	9.10E+03	1.75E+04	0	1	0
B2	0.6176	9.50E+03	1.60E+04	9.50E+03	1.60E+04	0	1	0
F2	1.2612	1.35E+04	6.20E+03	6.20E+03	1.35E+04	2	1	0
D1	0.9498	1.16E+04	6.50E+03	6.50E+03	2.07E+04	1	0	0
D3	0.9757	1.14E+04	9.80E+03	9.80E+03	2.02E+04	1	1	0
D3	0.8979	1.21E+04	9.50E+03	9.10E+03	2.00E+04	1	1	0
D4	1.3183	1.15E+04	8.80E+03	8.80E+03	2.14E+04	1	1	1
F1	0.8927	1.22E+04	1.25E+04	1.00E+04	1.50E+04	2	1	0
C2	0.8615	1.10E+04	8.70E+03	8.70E+03	1.68E+04	0	1	0
F1	1.1366	1.10E+04	1.40E+04	1.02E+04	1.52E+04	2	1	0
D1	1.0743	1.17E+04	8.40E+03	8.40E+03	2.13E+04	1	1	0
C4	0.7474	1.20E+04	1.05E+04	1.00E+04	1.52E+04	0	1	0
E4	1.3485	2.00E+04	1.83E+04	9.40E+03	2.00E+04	1	1	0
F8	1.1885	9.00E+03	1.50E+04	9.00E+03	2.20E+04	5	1	1
E1	0.7785	1.92E+04	1.40E+04	9.40E+03	1.40E+04	1	1	0
D3	1.0899	1.15E+04	8.50E+03	8.50E+03	1.88E+04	1	0	0
F7	1.3494	8.00E+03	9.10E+03	7.60E+03	1.43E+04	4	1	1
E3	1.2923	1.80E+04	1.72E+04	8.40E+03	1.80E+04	1	1	0
D1	1.3754	4.50E+03	7.80E+03	4.50E+03	1.54E+04	1	1	0
E1	1.0069	1.50E+04	1.50E+04	8.60E+03	1.50E+04	1	1	0
E3	1.0172	2.00E+04	1.80E+04	9.30E+03	2.00E+04	1	1	0
E3	1.1159	1.65E+04	1.75E+04	8.20E+03	1.75E+04	1	1	0
F2	1.0743	1.65E+04	1.13E+04	1.13E+04	1.90E+04	2	0	0
E3	0.8301	1.60E+04	1.42E+04	8.30E+03	1.60E+04	1	1	0
B4	0.3838	1.40E+04	2.08E+04	1.25E+04	2.08E+04	0	0	0
D1	1.0432	5.10E+03	7.70E+03	5.10E+03	1.55E+04	1	1	0
D1	0.9134	1.10E+04	9.30E+03	9.30E+03	2.05E+04	1	0	0
C3	0.6695	2.04E+04	1.05E+04	8.80E+03	1.05E+04	0	1	0
B2	0.8460	9.50E+03	1.80E+04	9.10E+03	1.80E+04	0	1	0
D1	1.0432	1.25E+04	8.50E+03	8.50E+03	2.04E+04	1	0	0
D3	1.0276	1.17E+04	7.80E+03	7.80E+03	2.00E+04	1	1	0
D2	0.5813	1.12E+04	1.54E+04	1.12E+04	2.00E+04	1	0	0
E1	0.8096	1.25E+04	1.62E+04	9.65E+03	1.62E+04	1	1	0
MIN	0.089	4500	4550	4500	8200	0	0	0
MAX	2.007	27800	20800	18800	27800	8	6	1
MEAN	0.857	13437.589	11004.610	8667.553	17025.709	0.780	0.851	0.046
STDEV	0.274	4400.553	3710.895	1871.823	2900.252	1.157	0.759	0.210

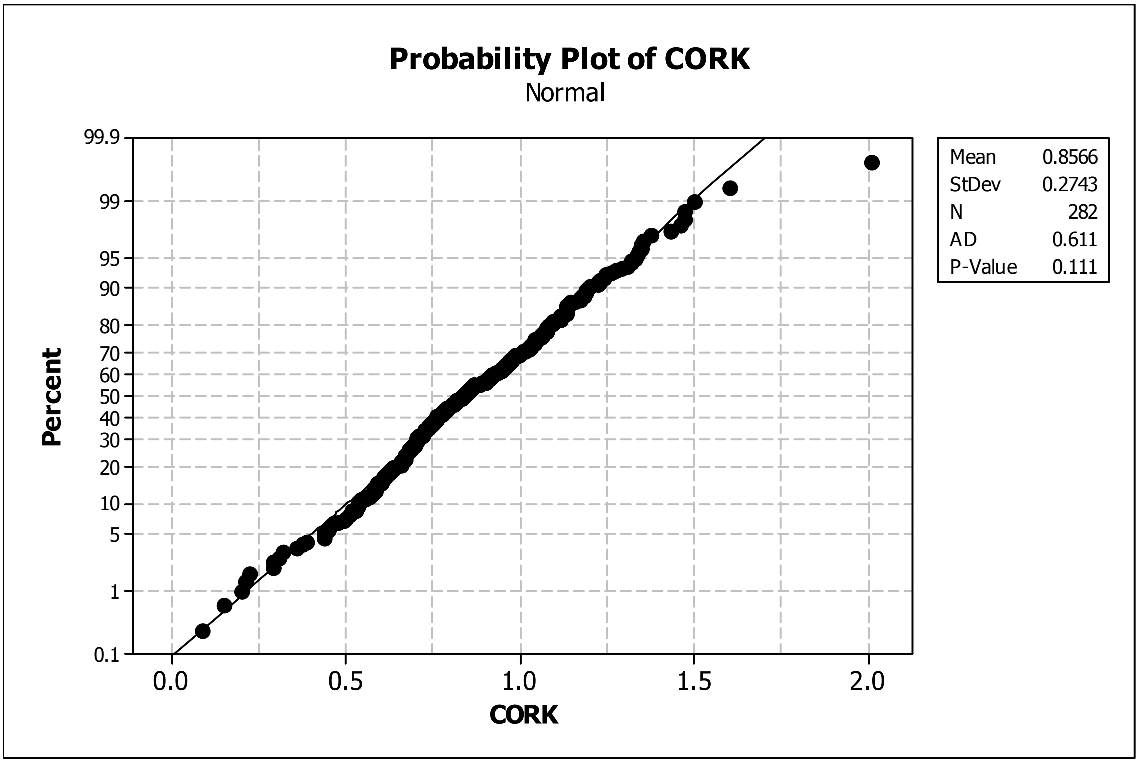
Table 5. Blasket Island's 80 whistles types with the calculations for all parameters measured in the spectrographic analysis.

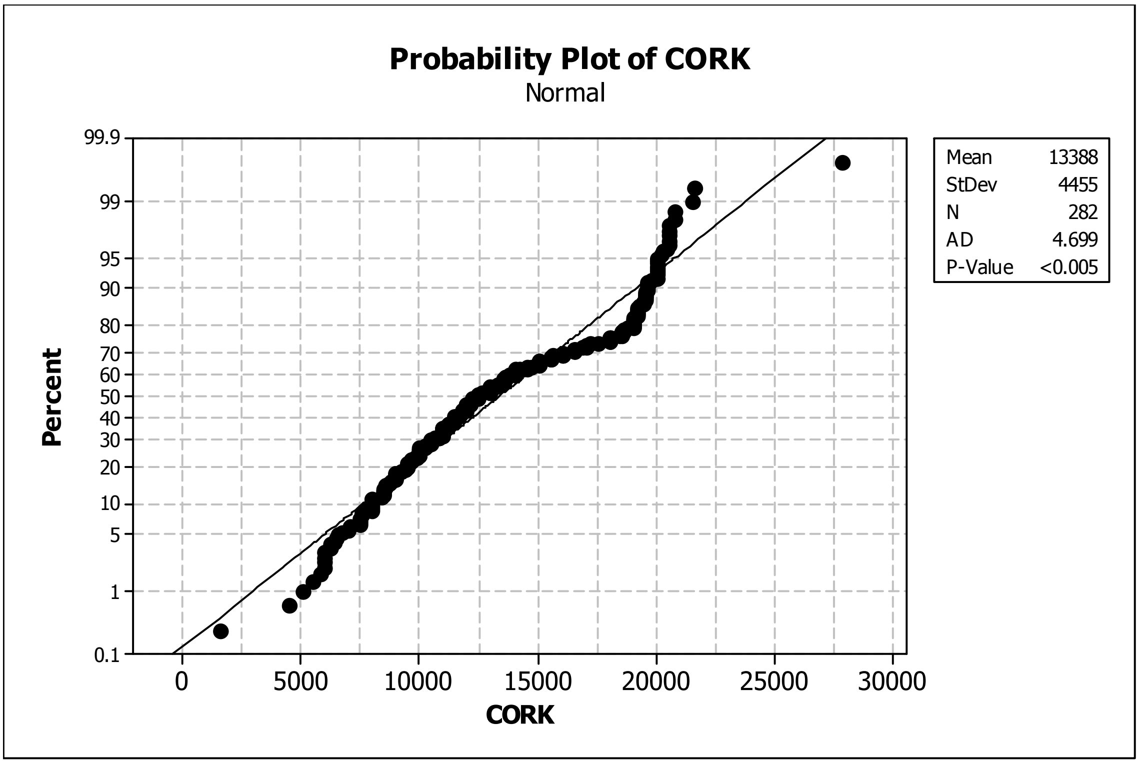
WHISTLE Type	Duration (s)	Start Freq (Hz)	End Freq (Hz)	Min Freq (Hz)	Max Freq (Hz)	Inflections	N. of Harmonics	Step
C5	0.9307	1.42E+04	9.45E+03	9.45E+03	1.42E+04	0	1	0
C5	0.7696	1.30E+04	9.50E+03	9.50E+03	1.30E+04	0	1	0
C1	0.9307	2.05E+04	9.20E+03	9.20E+03	2.05E+04	0	1	0
E1	1.0829	1.88E+04	1.75E+04	1.25E+04	1.88E+04	1	0	0
B1	0.8144	8.00E+03	1.65E+04	8.00E+03	1.65E+04	0	0	0
B1	0.7251	7.00E+03	1.55E+04	7.00E+03	1.55E+04	0	1	0
C1	0.7559	1.85E+04	9.15E+03	9.15E+03	1.85E+04	0	1	0
F1	0.7472	9.30E+03	1.50E+04	8.00E+03	1.50E+04	2	1	0
D4	0.4165	1.15E+04	9.80E+03	9.80E+03	1.35E+04	1	1	0
D4	0.5377	8.70E+03	1.03E+04	8.60E+03	1.28E+04	1	1	0
C5	0.8330	1.35E+04	9.00E+03	9.00E+03	1.35E+04	0	1	0
C5	0.8740	1.30E+04	6.40E+03	6.40E+03	1.30E+04	0	1	0
C4	0.9210	1.15E+04	9.50E+03	8.00E+03	1.15E+04	0	1	0
A2	1.0365	1.60E+04	9.50E+03	9.50E+03	1.60E+04	0	0	0
D1	1.2377	7.40E+03	9.10E+03	7.40E+03	1.78E+04	1	0	0
D1	1.4489	7.50E+03	1.75E+04	7.50E+03	1.92E+04	1	1	0
F2	0.5338	1.10E+04	8.00E+03	6.75E+03	1.14E+04	2	0	0
D1	1.2090	1.52E+04	1.52E+04	1.52E+04	1.97E+04	1	0	0
D1	1.1204	1.54E+04	1.54E+04	1.54E+04	2.00E+04	1	0	0
C1	0.7626	2.00E+04	9.00E+03	9.00E+03	2.00E+04	0	1	0
C1	0.8506	2.00E+04	6.30E+03	6.30E+03	2.00E+04	0	1	0
C1	0.7978	2.00E+04	8.20E+03	8.20E+03	2.00E+04	0	1	0
D1	0.7215	1.00E+04	8.00E+03	8.00E+03	1.65E+04	1	0	0
D3	0.9503	1.30E+04	1.10E+04	1.10E+04	2.00E+04	1	0	0
C1	0.7802	2.00E+04	7.20E+03	7.20E+03	2.00E+04	0	1	0
F8	0.9679	1.60E+04	1.55E+04	1.08E+04	1.86E+04	5	0	0
C1	0.8623	2.02E+04	7.50E+03	7.50E+03	2.02E+04	0	0	0
B1	0.8506	8.40E+03	1.90E+04	8.40E+03	1.90E+04	0	1	0
F4	1.0000	1.55E+04	1.55E+04	1.08E+04	1.55E+04	3	1	0
C5	1.2084	2.20E+04	6.00E+03	6.00E+03	2.20E+04	0	1	0
C5	0.7462	1.45E+04	4.50E+03	4.50E+03	1.45E+04	0	0	0
C1	1.0148	1.42E+04	8.65E+03	8.65E+03	1.42E+04	0	1	0
E1	1.6484	1.92E+04	1.38E+04	8.60E+03	1.92E+04	1	1	0
A4	0.9210	1.32E+04	1.33E+04	1.32E+04	1.33E+04	0	1	0
C1	0.7743	1.96E+04	1.20E+04	1.20E+04	1.96E+04	0	1	0
B2	1.0794	1.00E+04	1.85E+04	1.00E+04	1.85E+04	0	1	0
C5	0.8154	1.60E+04	6.00E+03	6.00E+03	1.60E+04	1	0	0
C5	0.9034	1.25E+04	9.30E+03	9.00E+03	1.25E+04	0	1	0
C5	0.8506	1.15E+04	5.50E+03	4.50E+03	1.15E+04	0	1	0
D1	0.5312	1.25E+04	1.23E+04	1.23E+04	1.60E+04	1	1	0
D1	1.0724	7.60E+03	1.10E+04	7.60E+03	1.73E+04	1	0	0
D4	0.9433	1.30E+04	9.50E+03	9.50E+03	1.85E+04	1	1	0
C1	0.6473	2.02E+04	8.80E+03	8.80E+03	2.02E+04	0	1	0
C5	0.6824	1.55E+04	9.20E+03	9.20E+03	1.55E+04	0	1	0
C5	0.3964	1.25E+04	9.00E+03	9.00E+03	1.25E+04	0	1	0
B5	0.6874	8.00E+03	1.60E+04	8.00E+03	1.60E+04	0	1	0
F2	0.4416	1.05E+04	9.00E+03	7.70E+03	1.26E+04	2	1	0

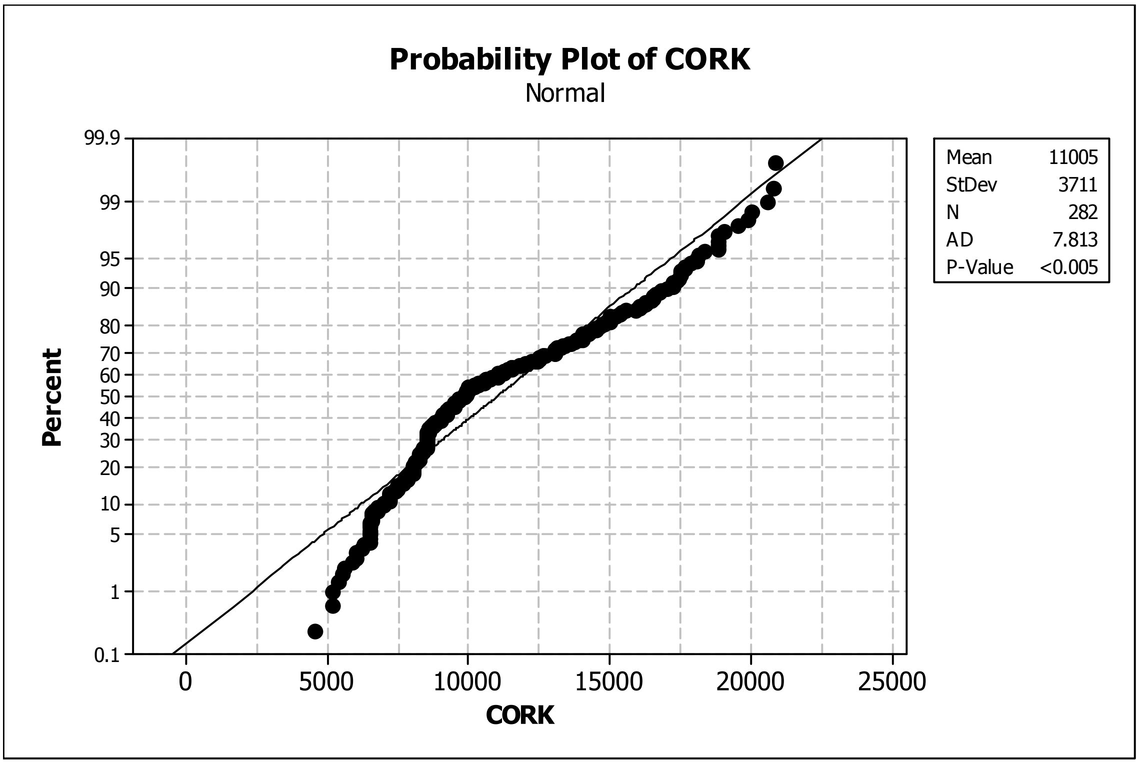
B2	0.7194	1.20E+04	1.30E+04	9.30E+03	1.30E+04	0	1	0
B1	1.0489	6.00E+03	2.00E+04	6.00E+03	2.00E+04	0	2	0
C1	0.6797	2.00E+04	9.20E+03	9.20E+03	2.00E+04	0	2	0
B1	0.7892	8.00E+03	1.70E+04	8.00E+03	1.70E+04	0	1	0
B1	0.8683	9.50E+03	1.80E+04	9.50E+03	1.80E+04	0	2	0
F1	1.1823	1.00E+04	1.20E+04	7.00E+03	1.66E+04	2	1	0
C5	1.0681	1.40E+04	6.80E+03	6.80E+03	1.40E+04	0	2	0
B5	0.4935	8.50E+03	1.80E+04	8.50E+03	1.80E+04	0	3	0
F2	1.0234	2.00E+04	9.30E+03	9.30E+03	2.00E+04	2	4	1
B1	0.5142	7.30E+03	1.13E+04	7.30E+03	1.13E+04	0	2	0
B1	0.6671	8.00E+03	1.80E+04	8.00E+03	1.80E+04	0	2	0
B1	0.7788	8.00E+03	1.90E+04	8.00E+03	1.90E+04	0	2	0
B1	0.7009	8.00E+03	1.85E+04	8.00E+03	1.85E+04	0	2	0
F3	0.8311	8.00E+03	9.00E+03	8.00E+03	1.85E+04	3	2	1
B3	0.9569	6.80E+03	1.53E+04	6.80E+03	1.53E+04	0	1	0
D4	1.4126	1.20E+04	7.00E+03	6.50E+03	1.26E+04	1	3	1
C5	1.1940	1.40E+04	5.50E+03	5.50E+03	1.40E+04	0	1	0
F6	1.2280	1.70E+04	1.35E+04	1.10E+04	1.75E+04	4	3	0
B1	0.7821	8.50E+03	1.80E+04	8.50E+03	1.80E+04	0	3	0
B1	0.6541	8.50E+03	1.80E+04	8.50E+03	1.80E+04	0	3	0
C5	1.2911	1.28E+04	6.50E+03	6.50E+03	1.28E+04	0	4	0
F4	1.3631	1.30E+04	1.16E+04	8.50E+03	1.30E+04	3	2	0
C3	0.9179	2.00E+04	1.00E+04	1.00E+04	2.00E+04	0	2	0
B5	0.9411	9.00E+03	1.80E+04	8.20E+03	1.80E+04	0	2	0
C5	1.0268	1.70E+04	6.00E+03	6.00E+03	1.70E+04	0	0	0
F4	1.3834	1.30E+04	9.50E+03	8.50E+03	1.30E+04	3	2	0
B3	1.1467	8.60E+03	1.25E+04	8.60E+03	1.55E+04	0	1	0
B1	0.7944	8.40E+03	1.75E+04	8.40E+03	1.75E+04	0	1	0
F2	0.9975	1.10E+04	8.00E+03	8.00E+03	1.18E+04	2	2	0
B5	1.2329	6.50E+03	1.50E+04	6.50E+03	1.50E+04	0	2	0
F4	1.1507	1.40E+04	8.80E+03	8.20E+03	1.40E+04	3	3	0
C5	1.1848	2.00E+04	9.00E+03	8.50E+03	2.00E+04	0	3	0
F2	1.1487	1.50E+04	9.00E+03	8.20E+03	1.50E+04	2	3	0
MIN	0.396	6000	4500	4500	11300	0	0	0
MAX	1.648	22000	20000	15400	22000	5	4	1
MEAN	0.913	12975	11610	8523.750	16499.375	0.663	1.275	0.038
STDEV	0.253	4459.225	4210.072	1972.067	2878.604	1.090	0.968	0.191

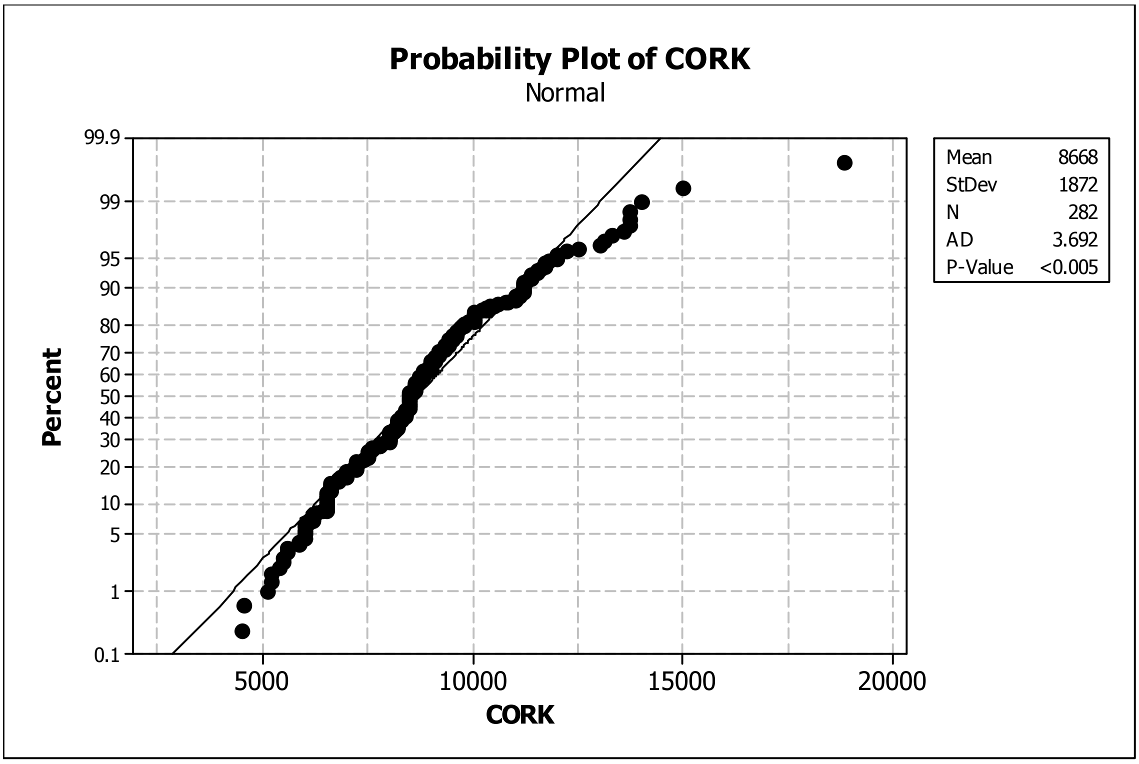
7.2 Appendix II

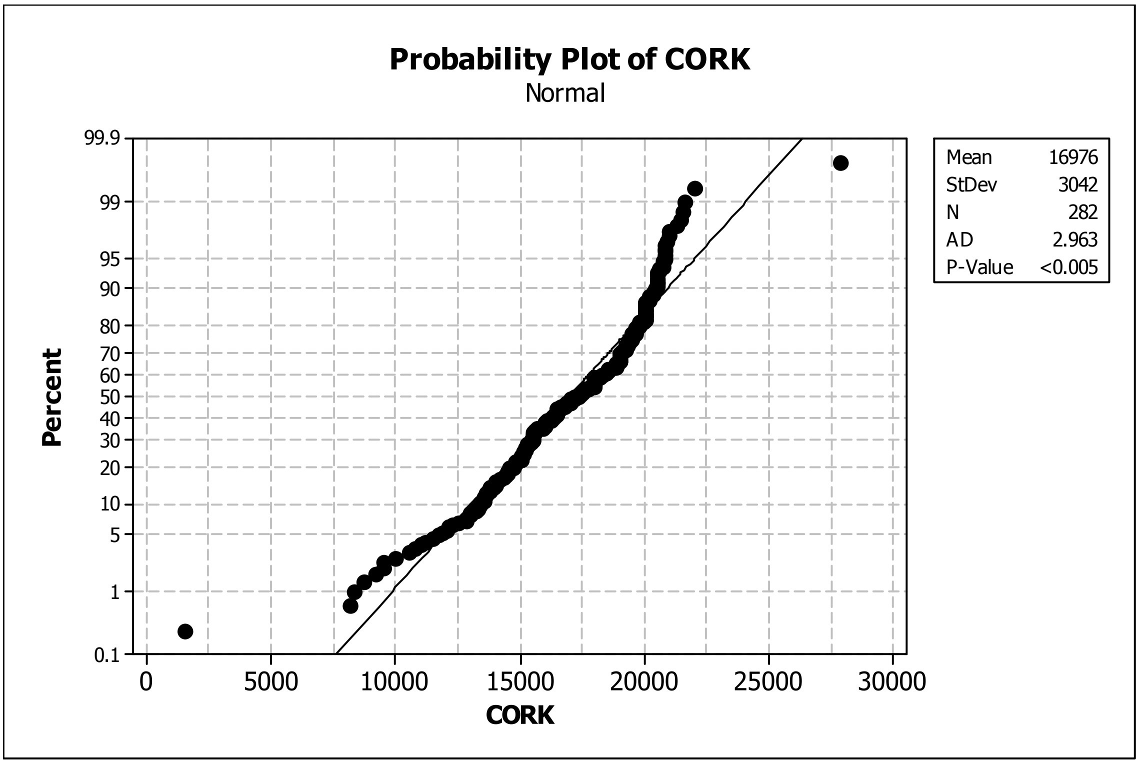
Figure 26-33. Normality test for Cork whistles for the following parameters: duration, start frequency, end frequency, minimum frequency, maximum frequency, inflections, number of harmonics and steps.

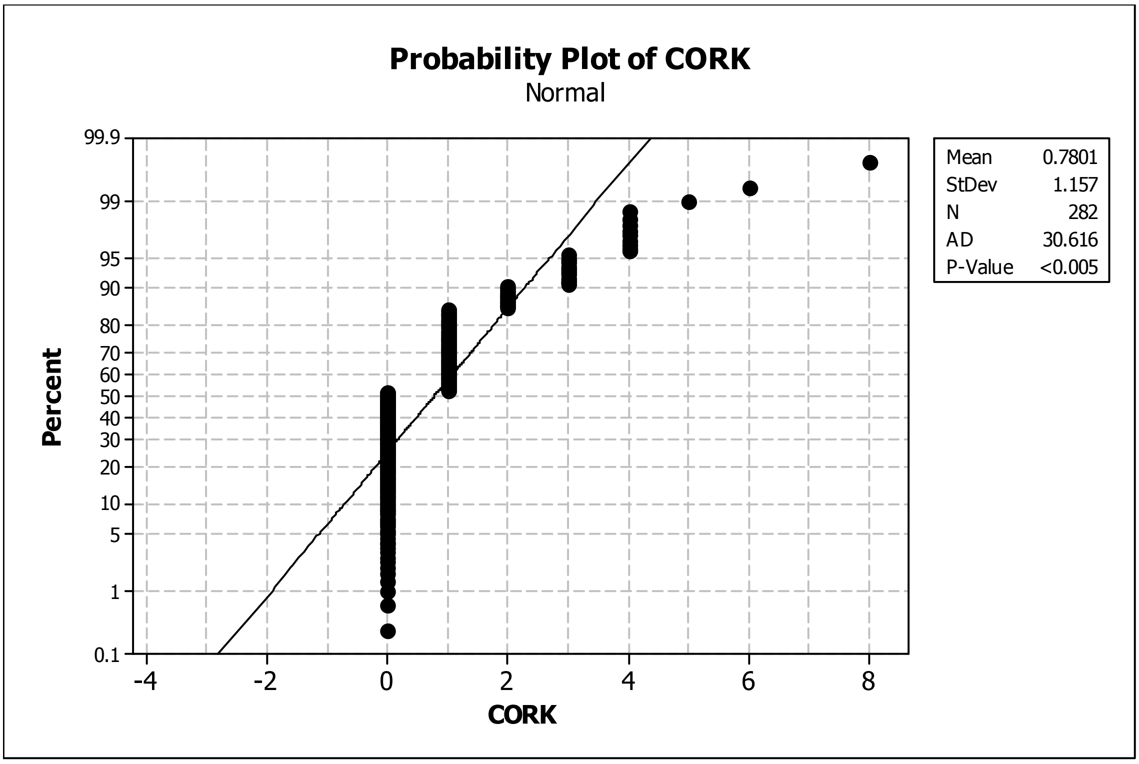


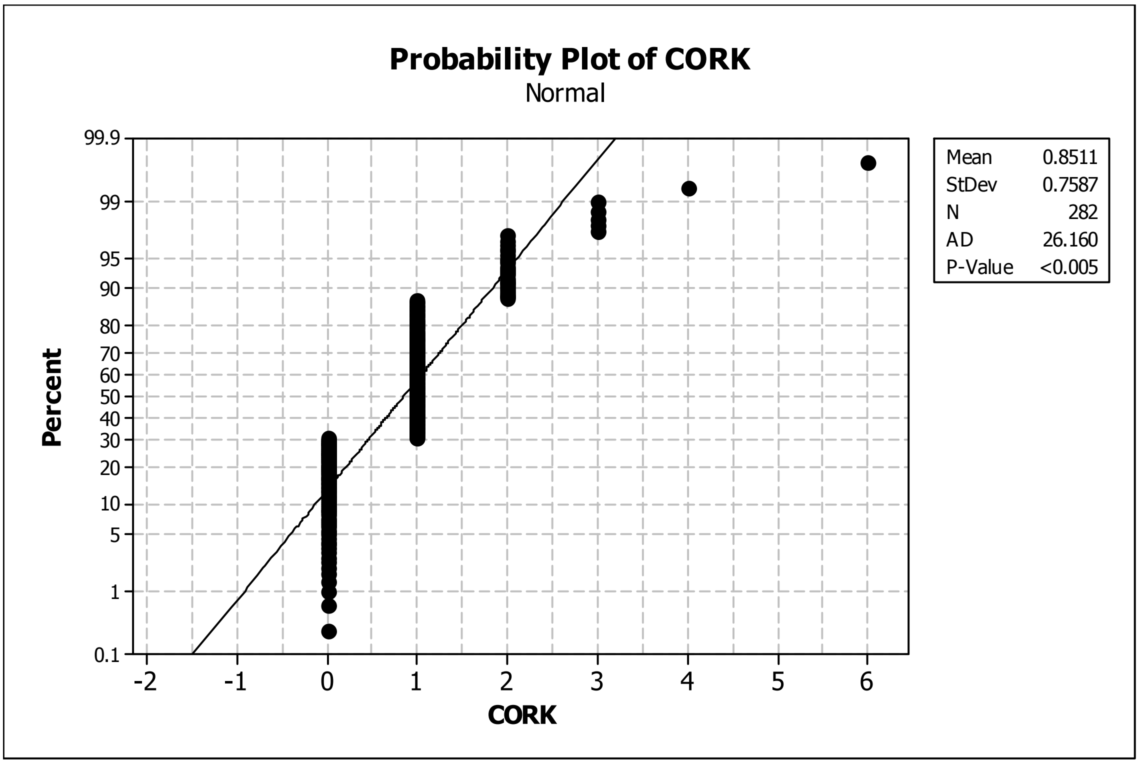



Probability Plot of CORK
Normal
Percent
CORK
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
0
5000
10000
15000
20000
25000
Mean 11005
StDev 3711
N 282
AD 7.813
P-Value <0.005


Probability Plot of CORK
Normal
Percent
CORK
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
5000
10000
15000
20000
Mean 8668
StDev 1872
N 282
AD 3.692
P-Value <0.005


Probability Plot of CORK
Normal
Percent
CORK
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
0
5000
10000
15000
20000
25000
30000
Mean 16976
StDev 3042
N 282
AD 2.963
P-Value <0.005


Probability Plot of CORK
Normal
Percent
CORK
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
-4
-2
0
2
4
6
8
Mean 0.7801
StDev 1.157
N 282
AD 30.616
P-Value <0.005


Probability Plot of CORK
Normal
Percent
CORK
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
-2
-1
0
1
2
3
4
5
6
Mean 0.8511
StDev 0.7587
N 282
AD 26.160
P-Value <0.005

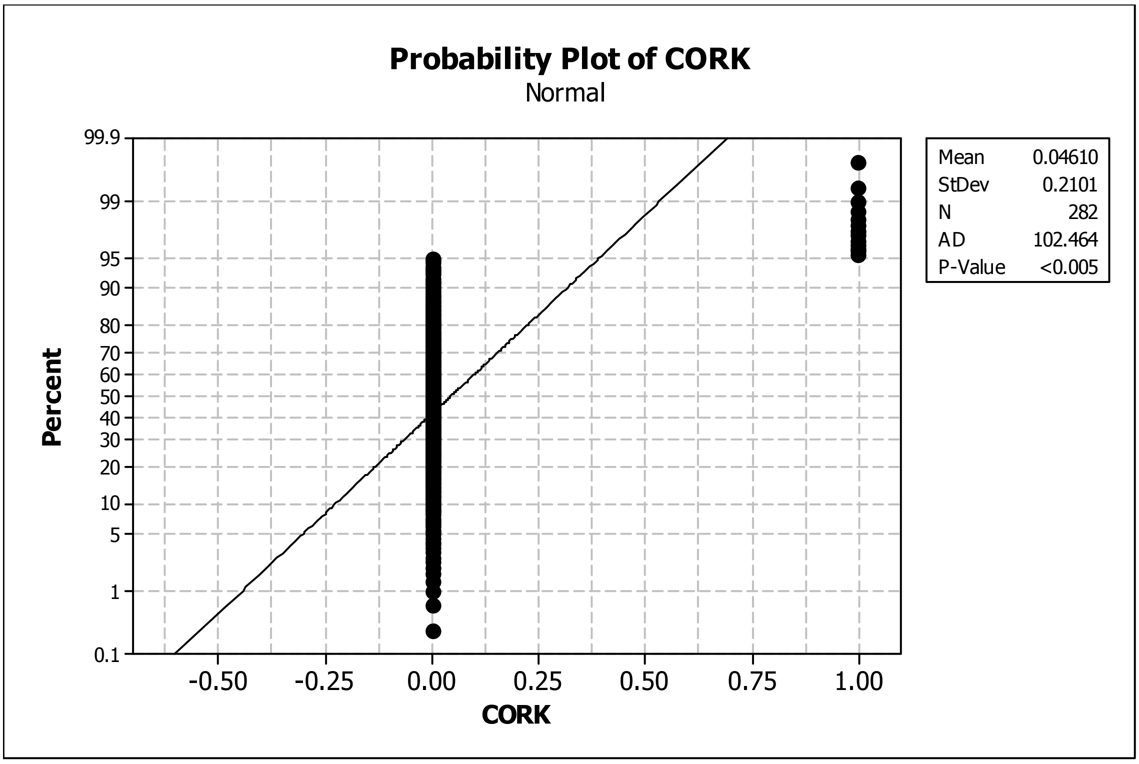
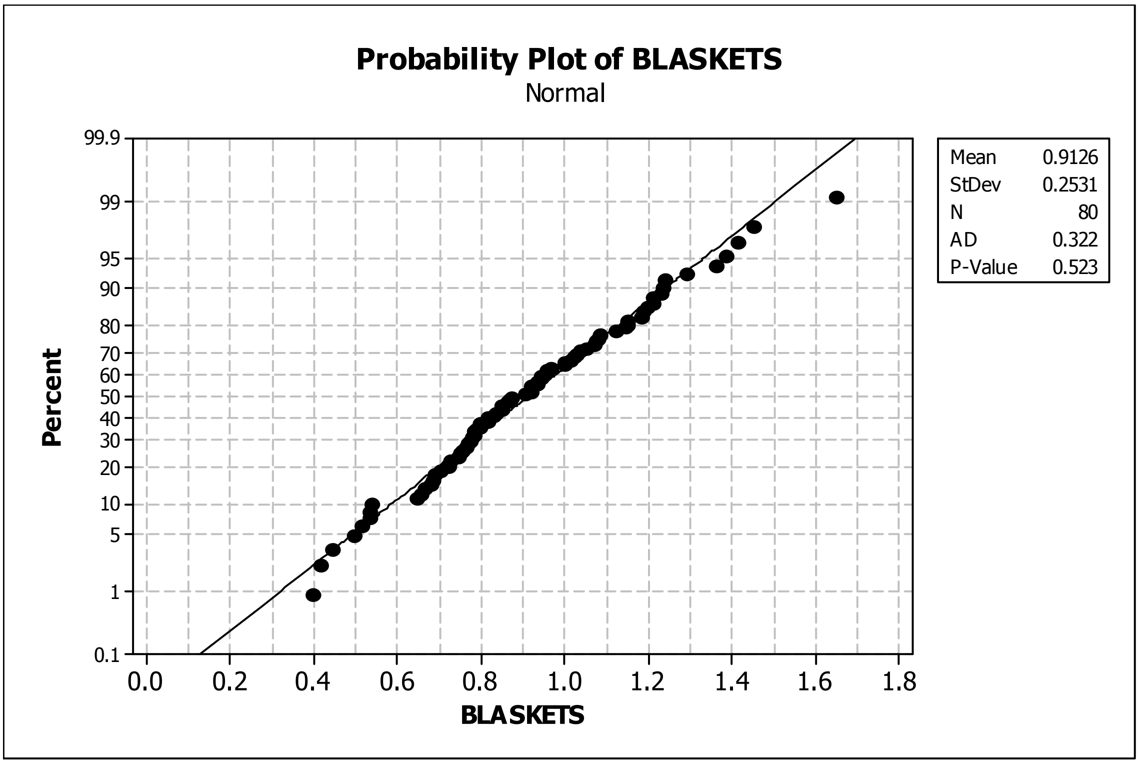
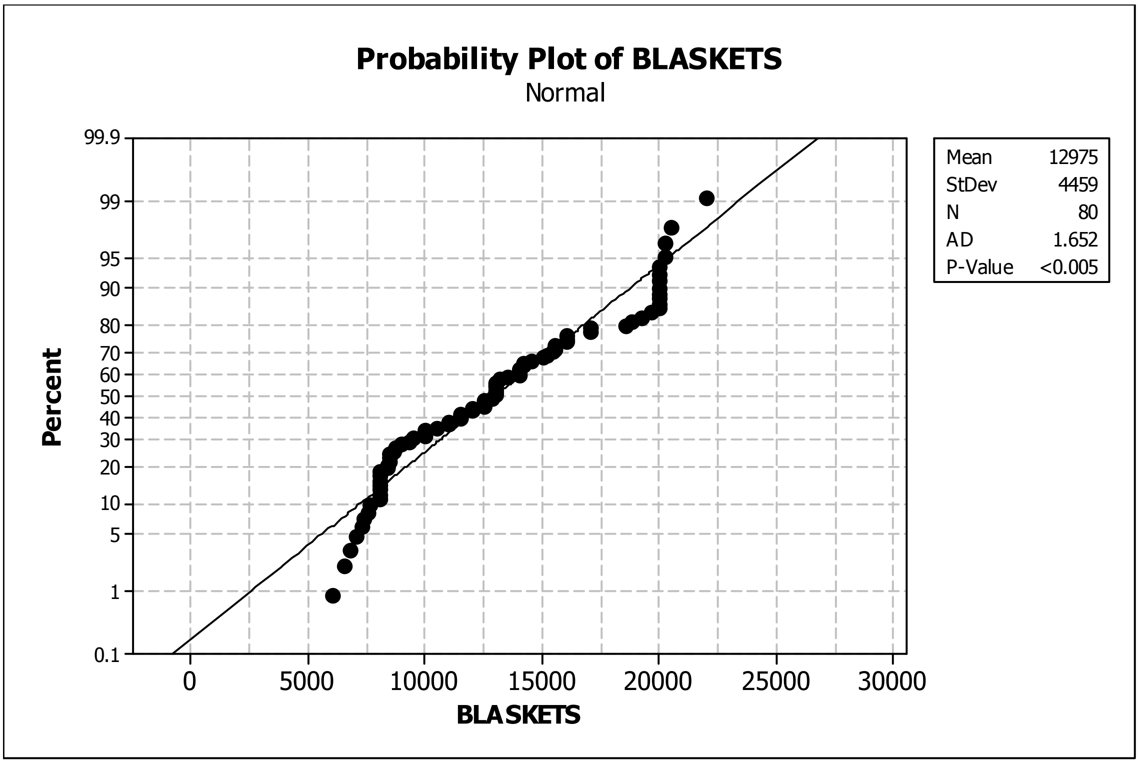
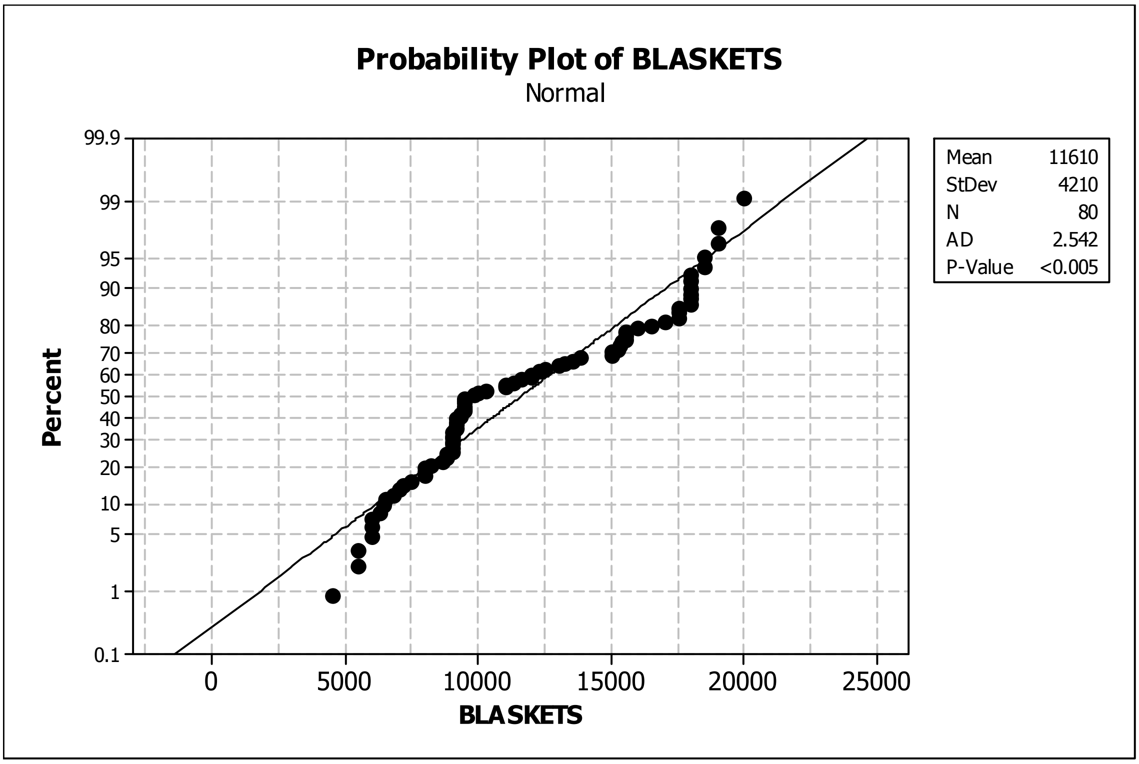
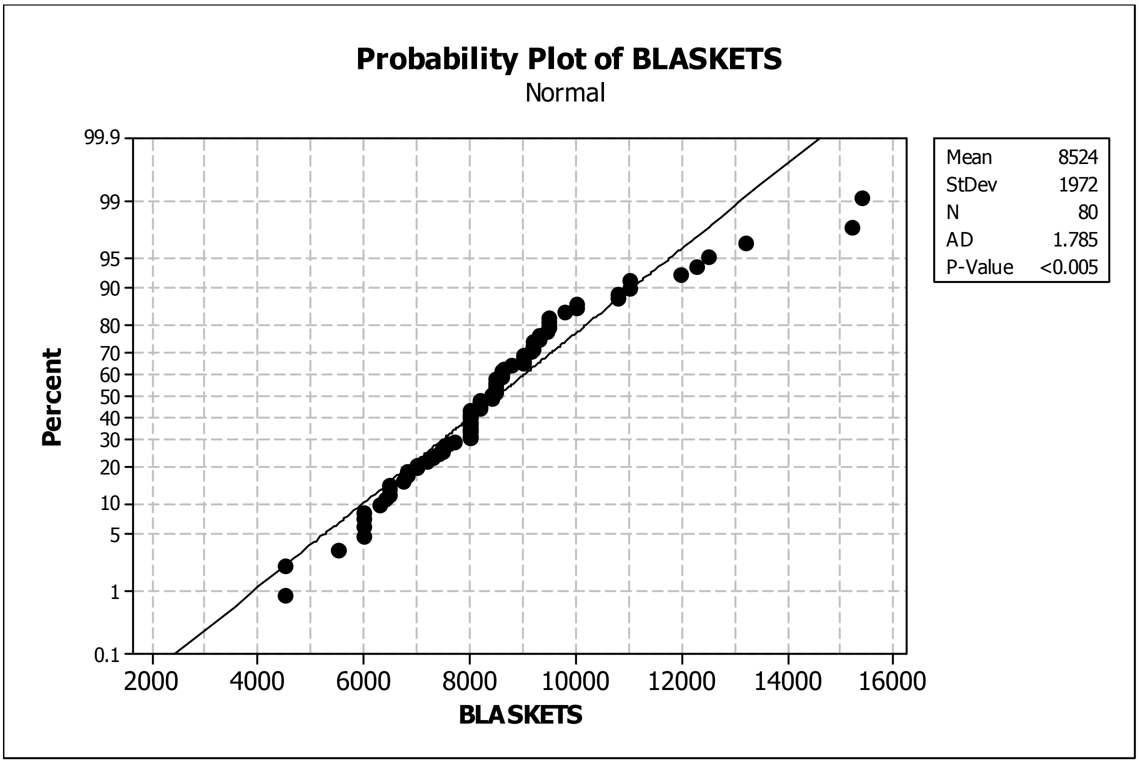

Probability Plot of CORK
Normal
Percent
CORK
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
-0.50
-0.25
0.00
0.25
0.50
0.75
1.00
Mean 0.04610
StDev 0.2101
N 282
AD 102.464
P-Value <0.005

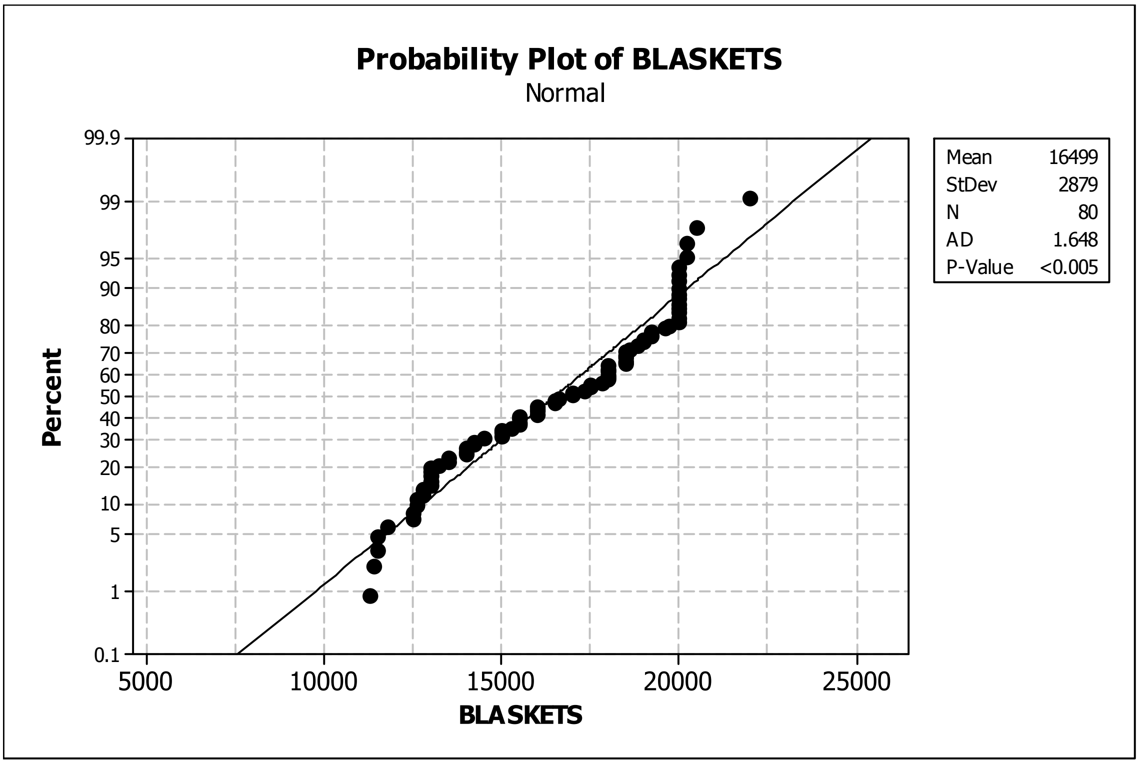
Figure 34-41. Normality test for Blasket Islands' whistles for the following parameters: duration, start frequency, end frequency, minimum frequency, maximum frequency, inflections, number of harmonics and steps.

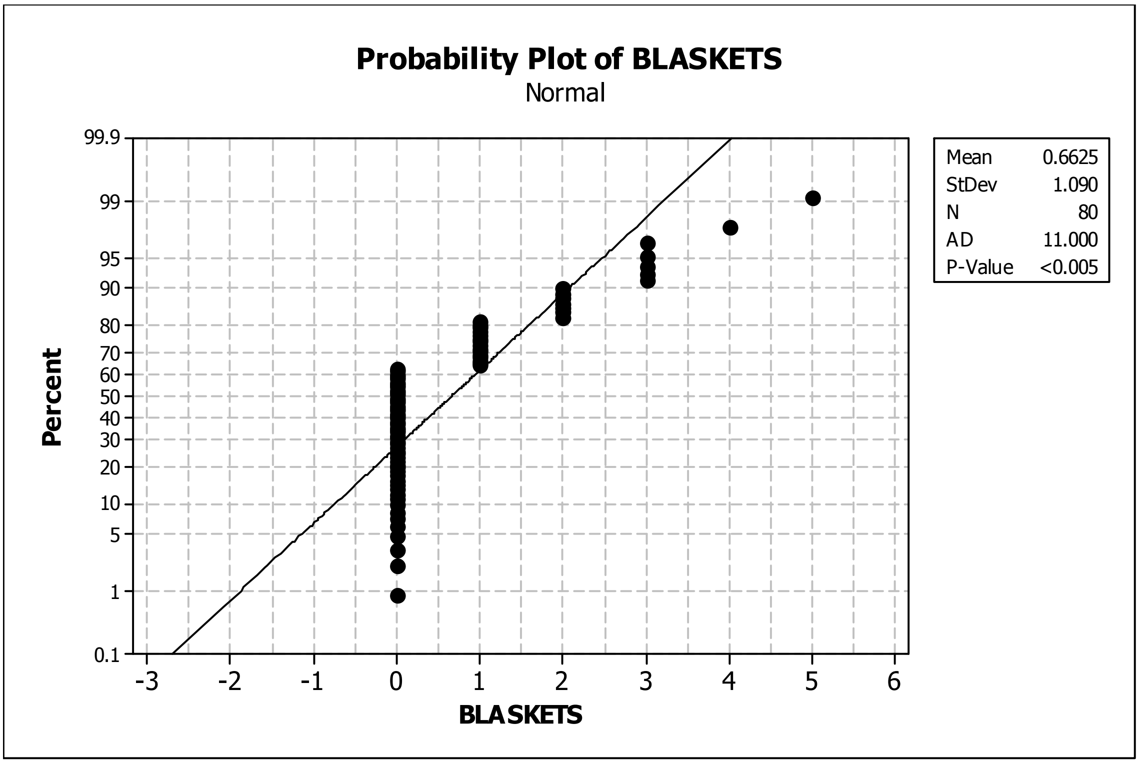


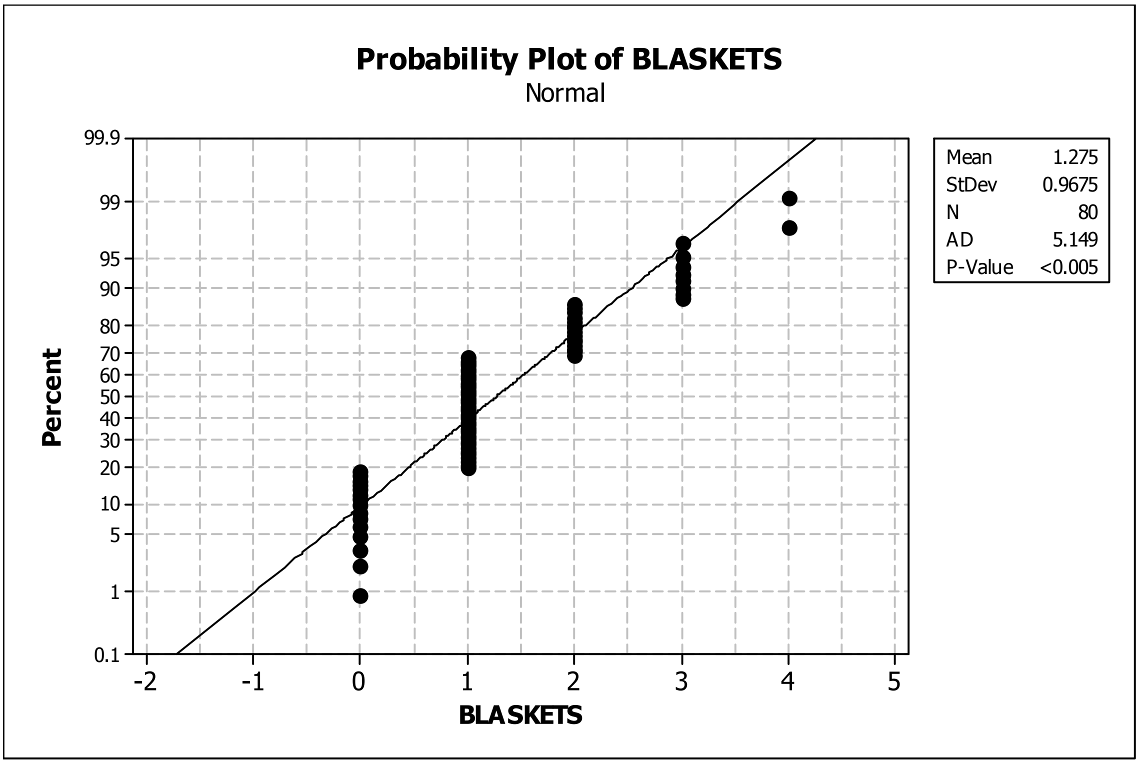



Probability Plot of BLASKETS
Normal
Percent
BLASKETS
Mean 11610
StDev 4210
N 80
AD 2.542
P-Value <0.005

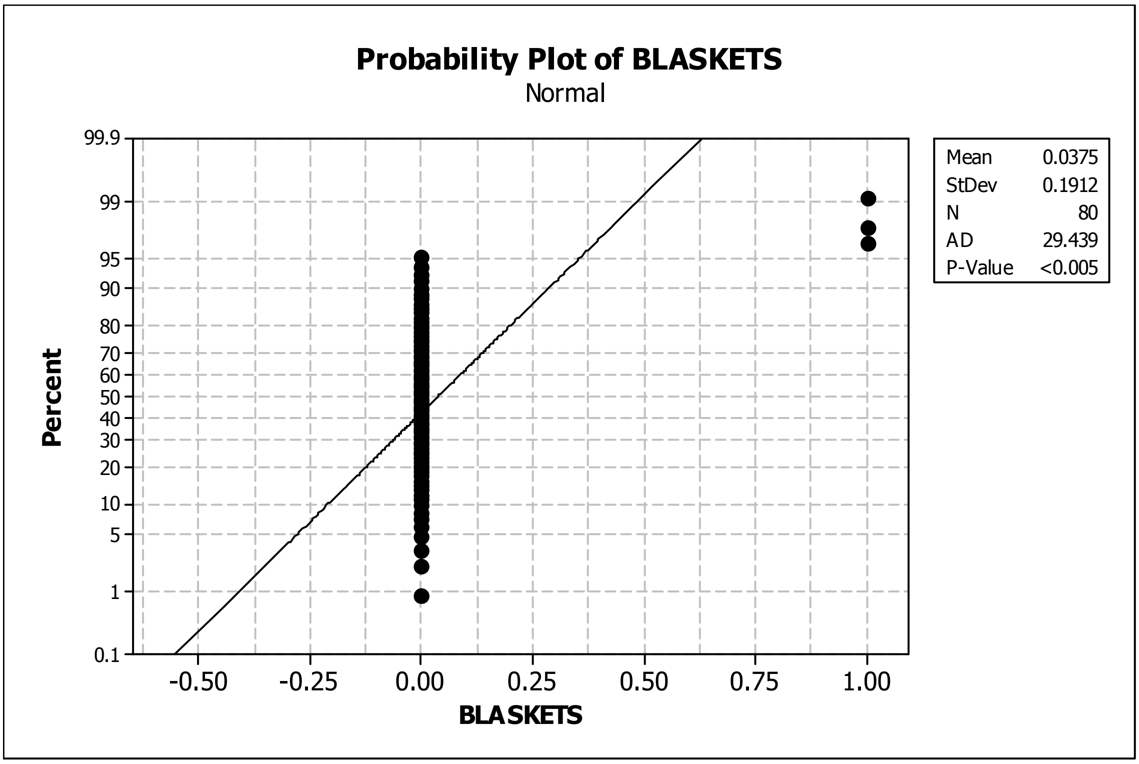

Probability Plot of BLASKETS
Normal
Percent
BLASKETS
Mean 8524
StDev 1972
N 80
AD 1.785
P-Value <0.005


Probability Plot of BLASKETS
Normal
Percent
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
5000
10000
15000
20000
25000
BLASKETS
Mean 16499
StDev 2879
N 80
AD 1.648
P-Value <0.005


Probability Plot of BLASKETS
Normal
Percent
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
-3
-2
-1
0
1
2
3
4
5
6
BLASKETS
Mean 0.6625
StDev 1.090
N 80
AD 11.000
P-Value <0.005



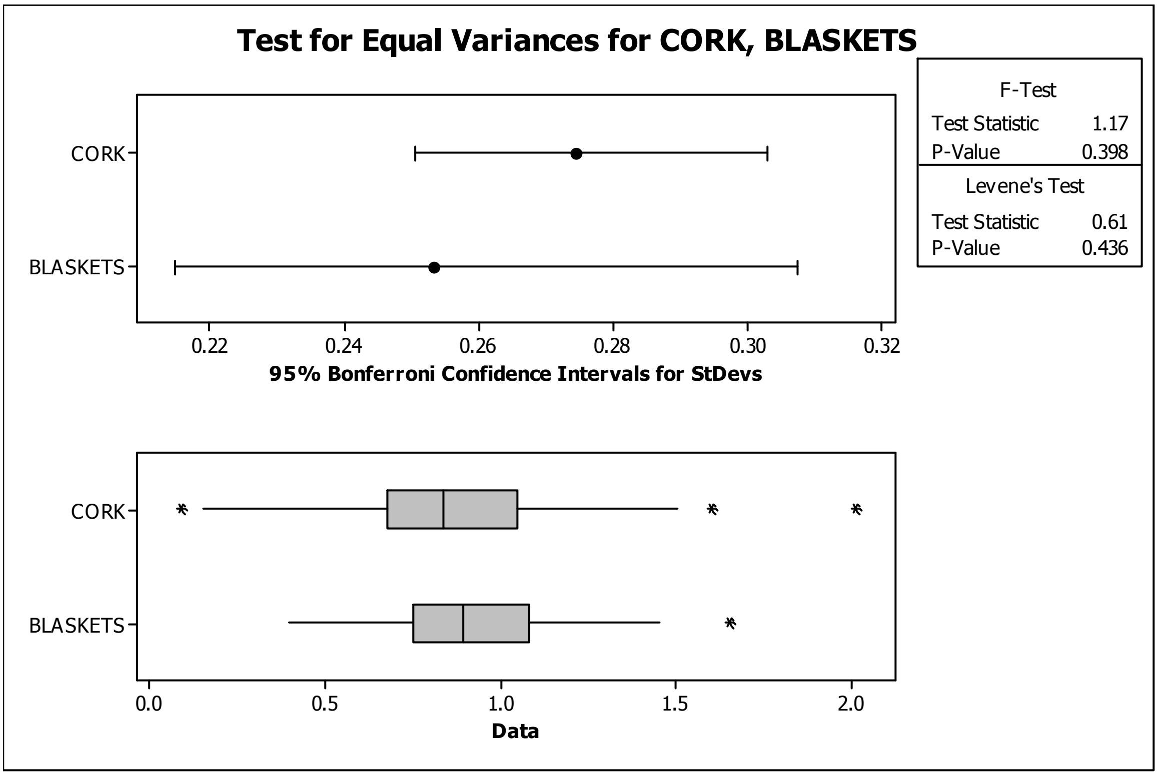
Probability Plot of BLASKETS
Normal
Percent
BLASKETS
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
-2
-1
0
1
2
3
4
5
Mean 1.275
StDev 0.9675
N 80
AD 5.149
P-Value <0.005

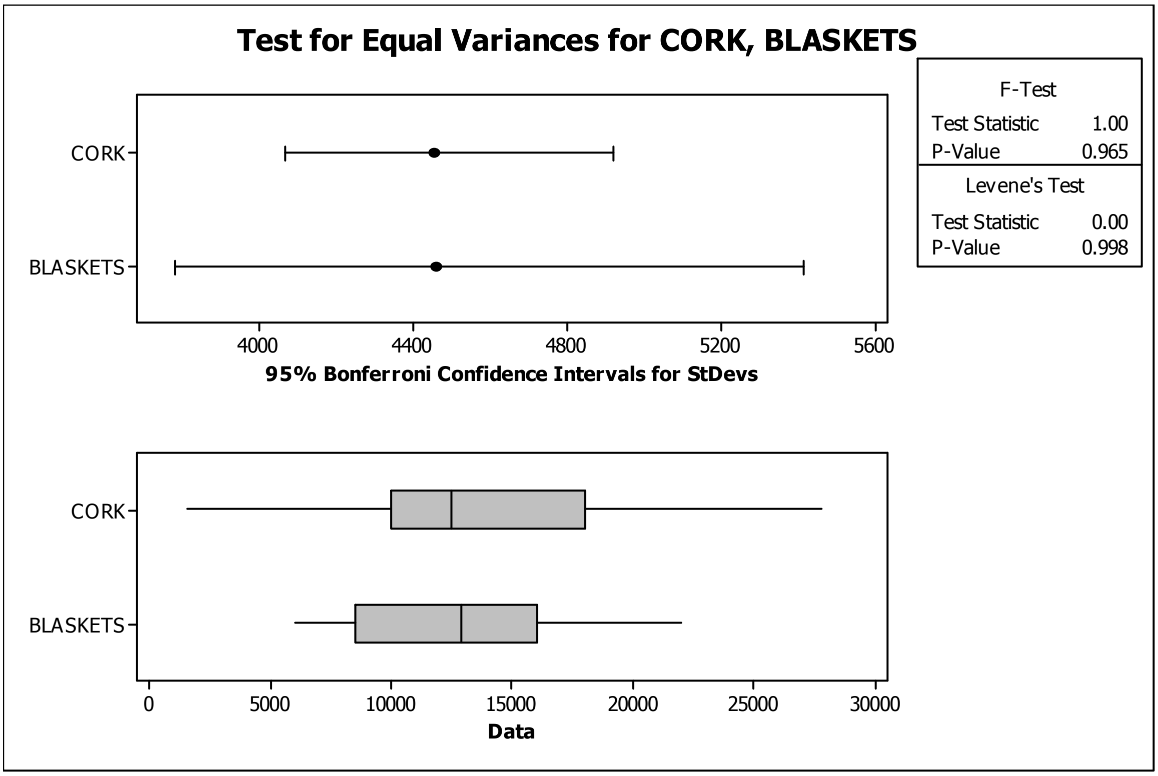


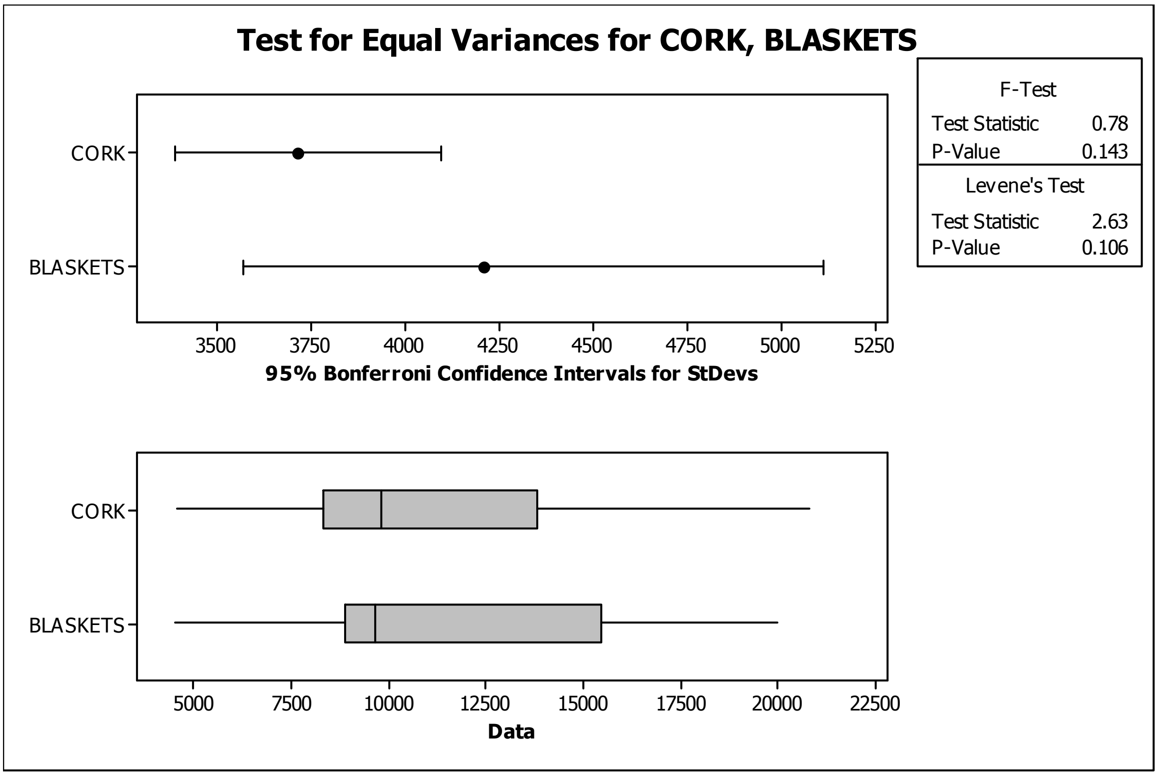
Probability Plot of BLASKETS
Normal
Percent
BLASKETS
99.9
99
95
90
80
70
60
50
40
30
20
10
5
1
0.1
-0.50
-0.25
0.00
0.25
0.50
0.75
1.00
Mean 0.0375
StDev 0.1912
N 80
AD 29.439
P-Value <0.005

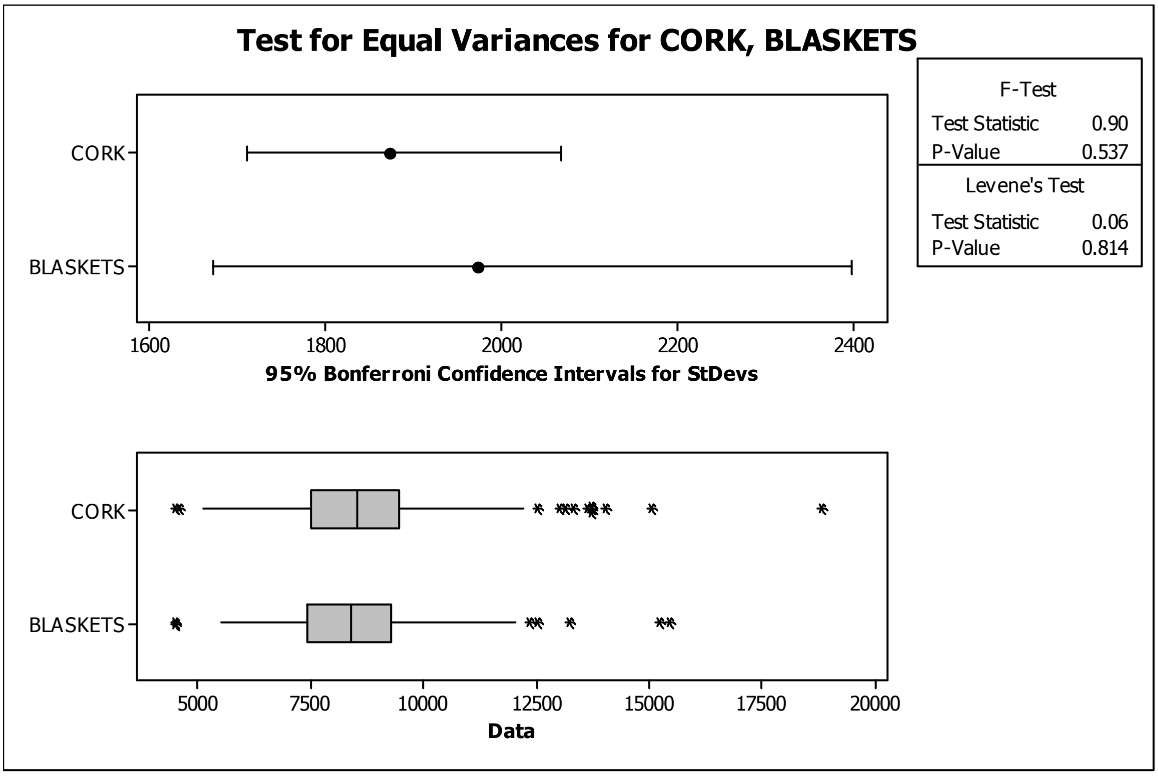
7.3 Appendix III

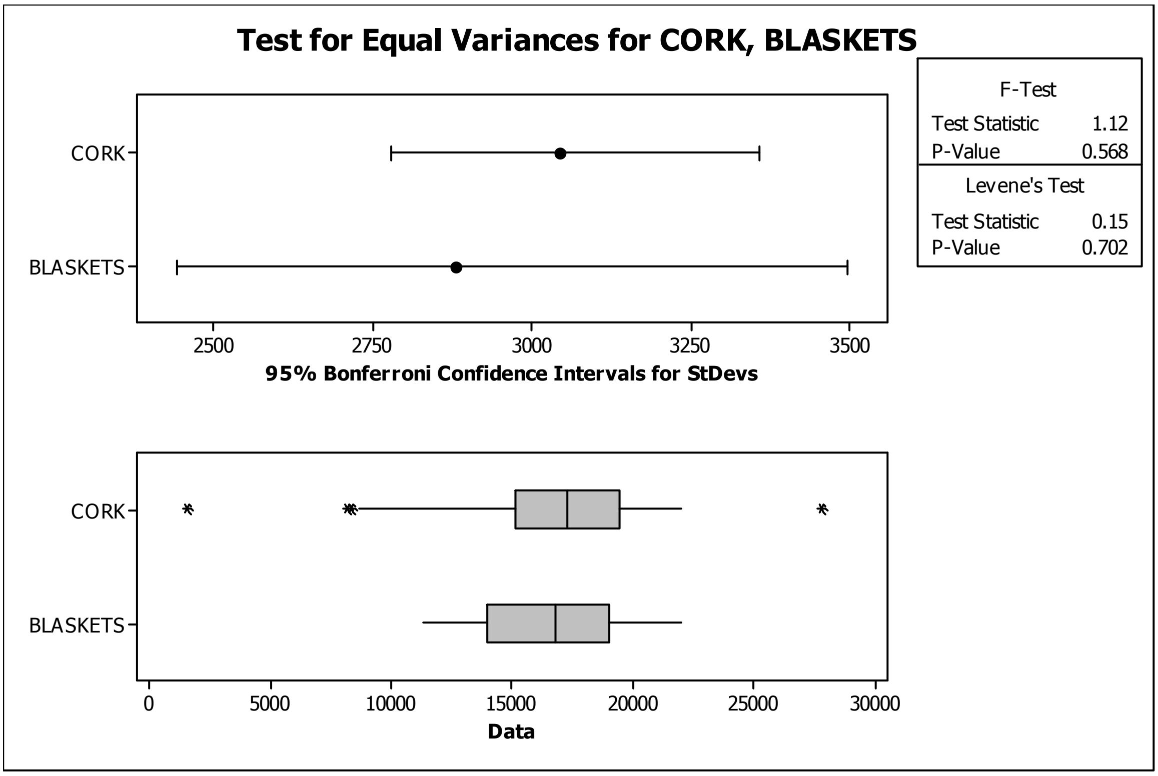
Figure 42-49. F-test for equal variances for Cork and Blasket Island whistles for the following parameters: duration, start frequency, end frequency, minimum frequency, maximum frequency, inflections, number of harmonics and steps.

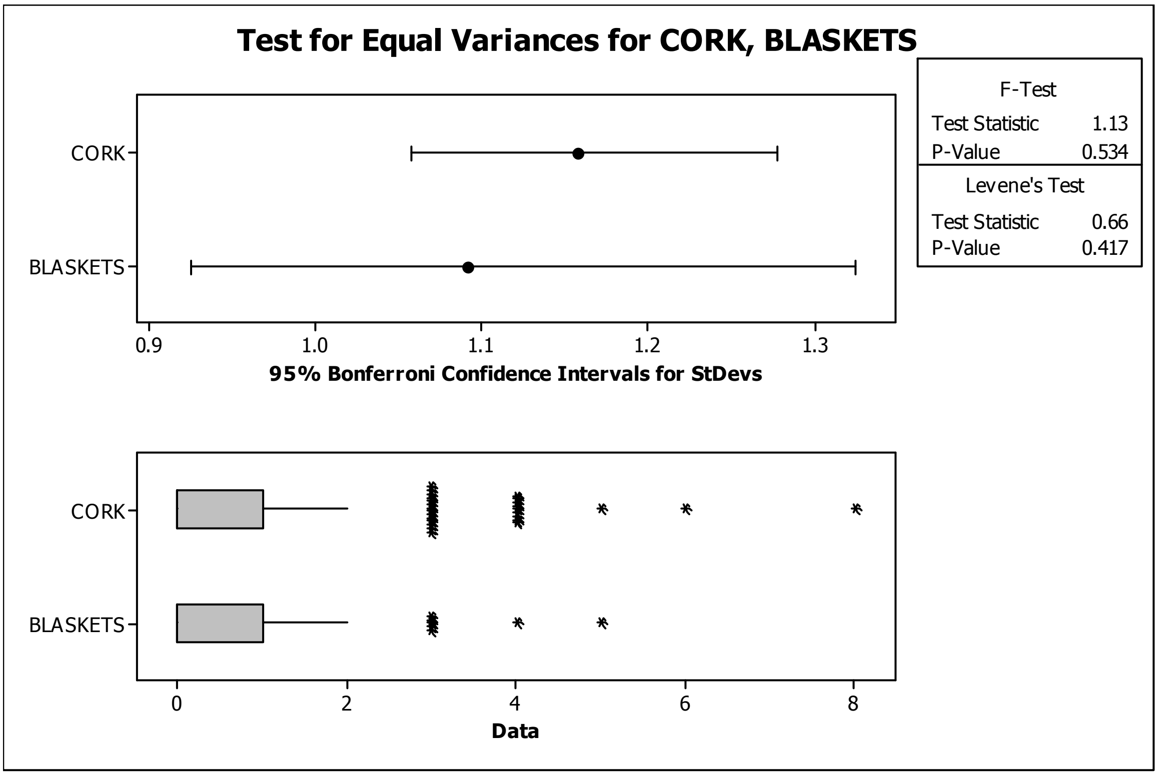


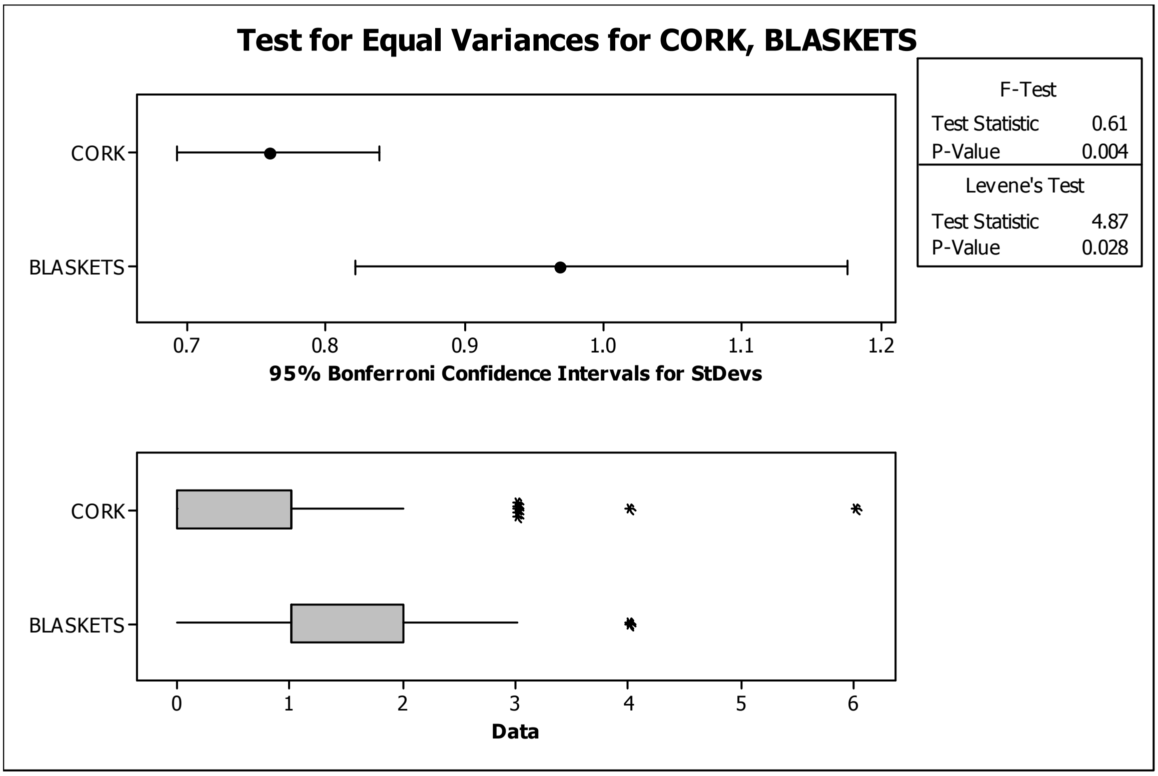


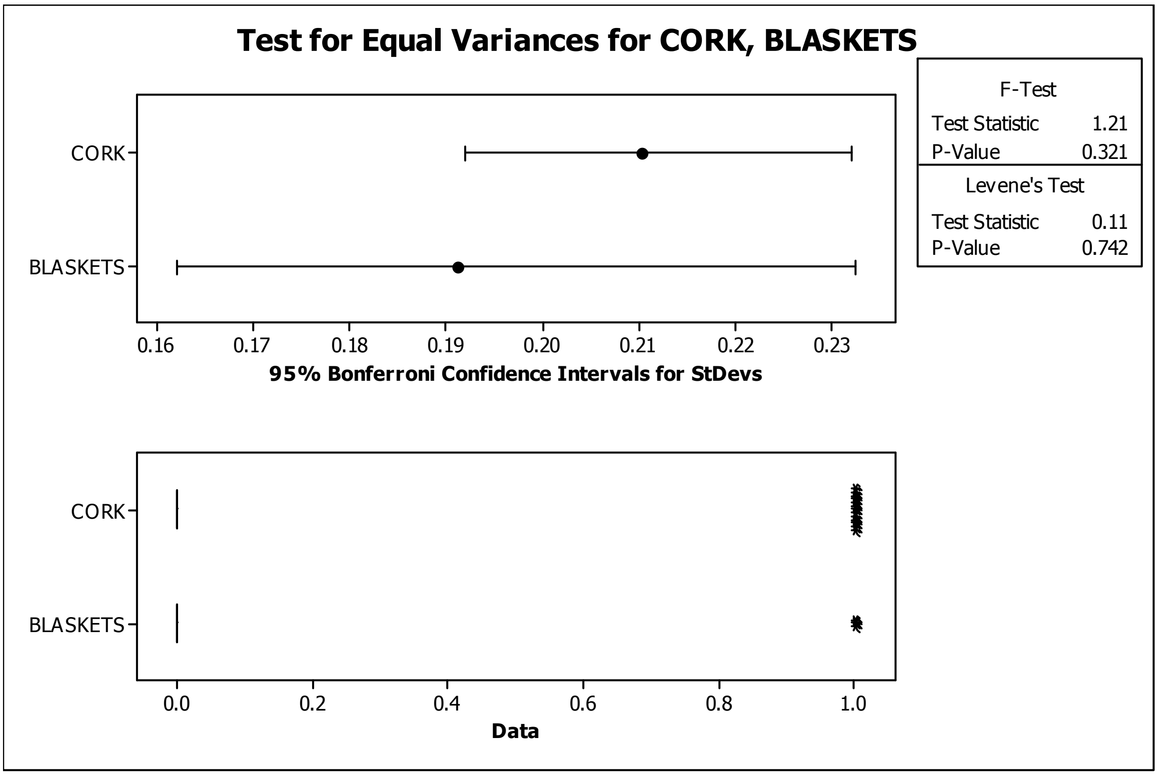

Test for Equal Variances for CORK, BLASKETS
CORK
BLASKETS
3500
3750
4000
4250
4500
4750
5000
5250
95% Bonferroni Confidence Intervals for StDevs
F-Test
Test Statistic 0.78
P-Value 0.143
Levene's Test
Test Statistic 2.63
P-Value 0.106
CORK
BLASKETS
5000
7500
10000
12500
15000
17500
20000
22500
Data


Test for Equal Variances for CORK, BLASKETS
CORK
BLASKETS
1600
1800
2000
2200
2400
95% Bonferroni Confidence Intervals for StDevs
F-Test
Test Statistic 0.90
P-Value 0.537
Levene's Test
Test Statistic 0.06
P-Value 0.814
CORK
BLASKETS
5000
7500
10000
12500
15000
17500
20000
Data


Test for Equal Variances for CORK, BLASKETS
F-Test
Test Statistic 1.12
P-Value 0.568
Levene's Test
Test Statistic 0.15
P-Value 0.702
CORK
BLASKETS
2500
2750
3000
3250
3500
95% Bonferroni Confidence Intervals for StDevs
CORK
BLASKETS
0
5000
10000
15000
20000
25000
30000
Data


Test for Equal Variances for CORK, BLASKETS
F-Test
Test Statistic 1.13
P-Value 0.534
Levene's Test
Test Statistic 0.66
P-Value 0.417
CORK
BLASKETS
0.9
1.0
1.1
1.2
1.3
95% Bonferroni Confidence Intervals for StDevs
CORK
BLASKETS
0
2
4
6
8
Data


Test for Equal Variances for CORK, BLASKETS
F-Test
Test Statistic 0.61
P-Value 0.004
Levene's Test
Test Statistic 4.87
P-Value 0.028
CORK
BLASKETS
0.7
0.8
0.9
1.0
1.1
1.2
95% Bonferroni Confidence Intervals for StDevs
CORK
BLASKETS
0
1
2
3
4
5
6
Data


Test for Equal Variances for CORK, BLASKETS
F-Test
Test Statistic 1.21
P-Value 0.321
Levene's Test
Test Statistic 0.11
P-Value 0.742
CORK
BLASKETS
0.16
0.17
0.18
0.19
0.20
0.21
0.22
0.23
95% Bonferroni Confidence Intervals for StDevs
CORK
BLASKETS
0.0
0.2
0.4
0.6
0.8
1.0
Data

7.4 Appendix IV

Table 6. Statistical analysis results for all parameters measured.

	t-test		F-test	Wilcoxon	
	t value	**P value**	**F value**	**P value**	**W value**
Duration (s)	-1.64	0.103	1.17	0.0908	49785.5
Start Freq (Hz)	0.73	0.465	1	0.5097	51728.0
End Freq (Hz)	-1.25	0.212	0.78	0.2330	50197.5
Min Freq (Hz)	0.6	0.549	0.9	0.3242	51997.5
Max Freq (Hz)	1.25	0.212	1.12	0.1307	52431.5
Inflections	0.81	0.417	1.13	0.1869	52163.0
N. of Harmonics	-4.14	0	0.61	0.0002	48407.0
Step	0.33	0.742	1.21	0.7428	51280.0